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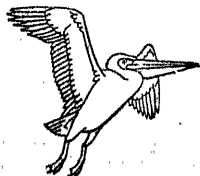


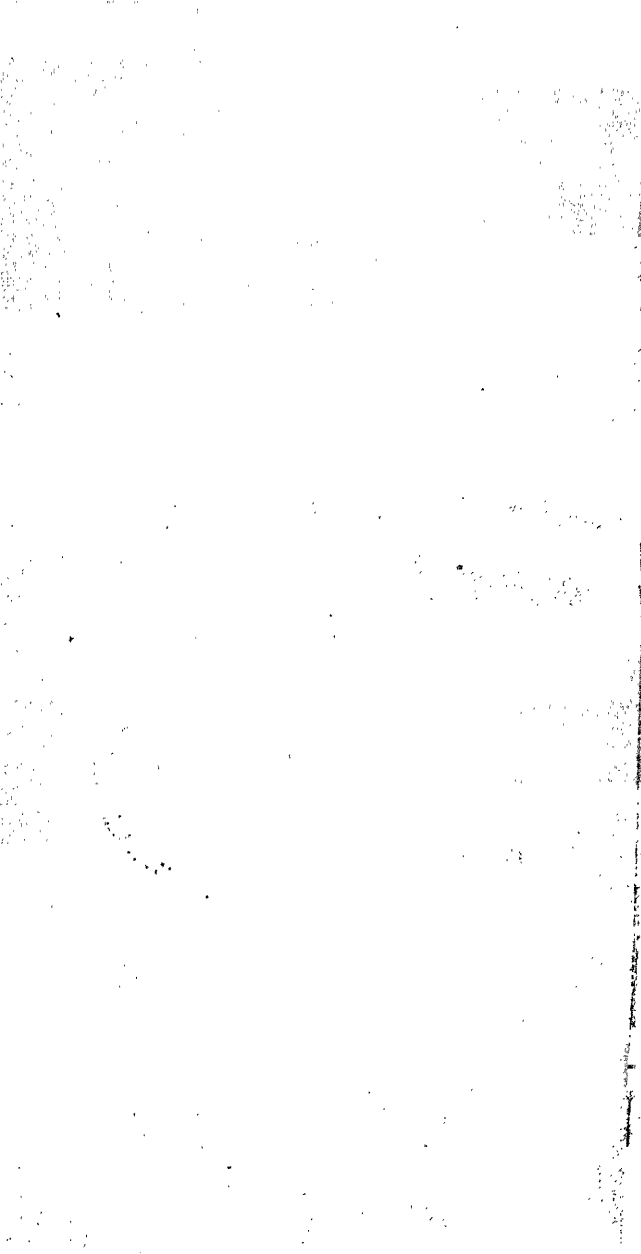
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MINERALS IN INDUSTRY

W. R. JONES





*W. R. JONES*

# (MINERALS IN INDUSTRY)

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## PREFACE

REFERENCE to 'this materialistic age' is frequently made under the popular misconception that material things have inherent power in their effect on man, instead of realizing fully that those effects are dependent on the use made of them.

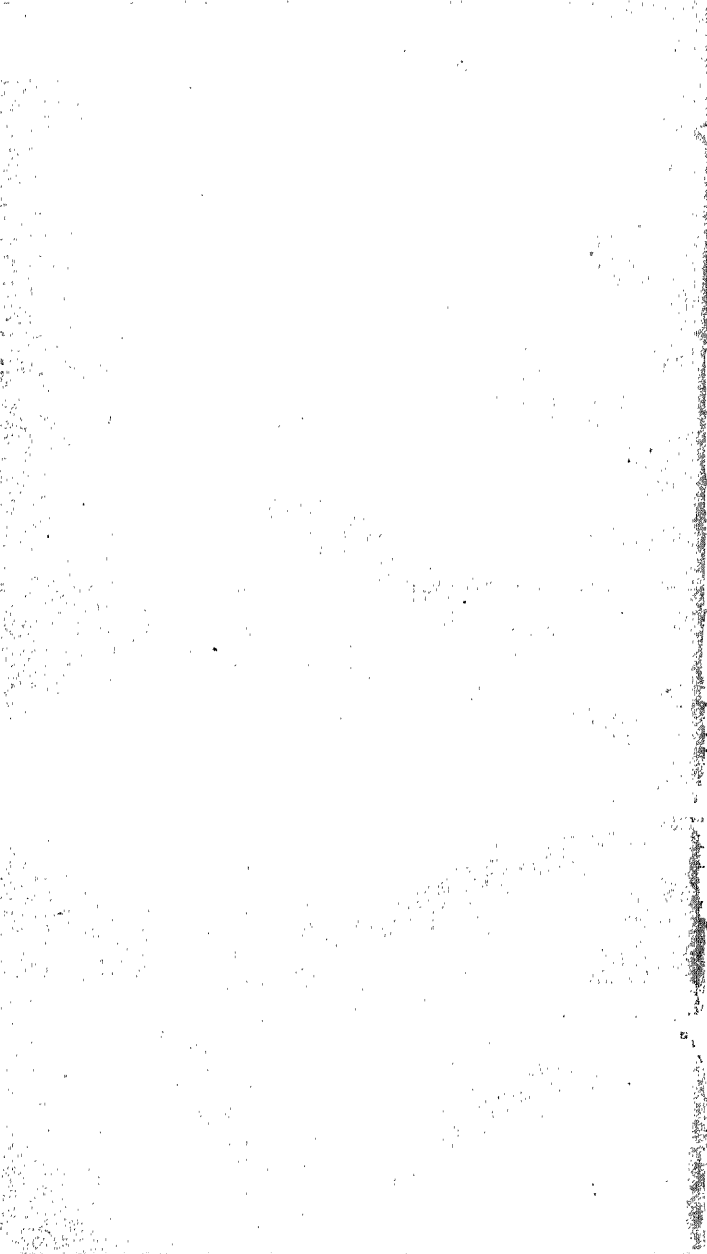
This small book is concerned with the minerals that supply most of the materials which are as essential to modern industries as food is to man.

The general reader cannot be expected to become interested in minerals which, although of great scientific importance to the geologist, are of little or no economic value, but it is reasonable to presume that there are occasions when he would welcome the opportunity of learning something about the natural sources of the materials he sees around him in almost daily use. It is for that reason that the industrial uses of the mineral products are first described, in order, as it were, to whet the appetite before proceeding to the assimilation of the more solid, if less palatable, descriptions of the minerals, their mode of occurrence, the parts of the world in which they are obtained, and the quantities in which they are produced.

A book of this nature is largely a compilation of information from a large number of sources, and although space makes it impossible to acknowledge most of those consulted, it would be unpardonable to omit special reference to the excellent statistics supplied by the Mineral Resources Department of the Imperial Institute, London; those published in *Minerals Yearbook* of the United States of America; and in the *Mineral Industry*.

My colleagues, Professor H. H. Read, F.R.S., and Dr H. J. T. Ellingham, have made helpful suggestions; and Dr (now Professor) David Williams, also a colleague, has been so indefatigable in collecting valuable information incorporated in this volume that any merit it has is in very large measure due to him, while for its imperfections the author alone is responsible.





## PREFACE TO THE SECOND EDITION

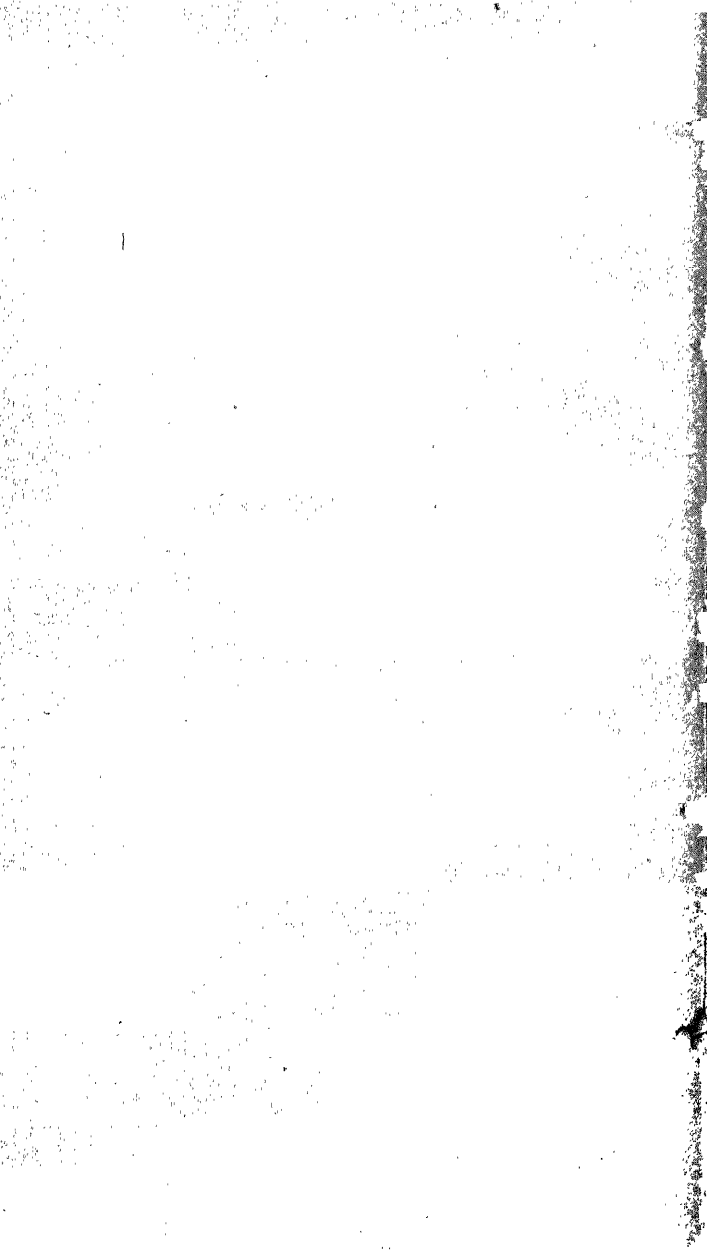
SINCE the publication of the first edition great changes in the mineral industry have taken place as the result of the Second World War and of the separation, with its attendant trade restrictions, of the Western and Eastern Powers who are the chief producers and consumers of minerals and mineral products.

During and after the war, several new uses were found for minerals and for the metals many of them contain. These new industrial applications have been incorporated in the Second Edition and the part dealing with 'Uranium: radium and plutonium' has been entirely rewritten.

There have been notable changes in the last few years in the mineral-producing centres of the world. For the most part these changes will prove to be of a transitory nature, for neither political nor geographical boundaries can remain the ultimate determining factors in the mineral world. No single nation, or even empire, possesses adequate supplies of all the minerals or mineral products it requires for its industrial and agricultural needs. There is not, for example, a single tin-mine in Canada or in the United States of America, so that the whole of the North American Continent is dependent on imported tin.

Spectacular increases of mineral production in some countries during abnormal years, and decreases in other countries, present a distorted picture of an industry which is slowly but inevitably regaining the more or less normal state it had during the five-year period preceding the Second World War. The diagrams showing the world average production for various minerals for the quinquennial period ended in 1938 have thus been reproduced in the Second Edition, and the latest figures available have been added in the context.

The author welcomes this opportunity of acknowledging his indebtedness to the Mineral Resources Department of the Imperial Institute, London, for allowing him to use the figures they supplied of the post-war mineral production of the various countries.



## PREFACE TO THE THIRD EDITION

SINCE the publication of the second edition the mineral industry is slowly and inevitably approaching a more normal state. The spectacular fluctuations in the production and in the price of minerals during the seven years following the Second World War are giving place to steadier conditions, and this in spite of unsettled conflicts in parts of Asia and disturbances in other continents.

The industry, more than ever before, has become the keystone of military security, and among the most important of all priorities in military planning is the provision for the supply of minerals in general, and of uranium minerals in particular.

Mineral production figures for any one year for almost any country can present a highly misleading conception of the state of that country's mineral industry. A far more reliable picture is presented by taking the average annual figures for a period of years, and especially for a period of more or less normality. Those for two quinquennial periods are given in this book, namely, the figures for 1934-8 as representing the pre-war period, and the annual averages of the industrial minerals for the chief producing countries for the five-year period 1948-52. There is a time lag in the availability of reasonably reliable figures later than 1952 for most countries.

Recent discoveries of economically important mineral deposits, and new uses for several minerals, will be found mentioned in the context.

The author once again welcomes the opportunity of acknowledging, as he has done in the earlier editions, his indebtedness to the Mineral Resources Department of the Imperial Institute, London, for permission to make use of the mineral statistics it has recently published.



## INTRODUCTION

ARCHAEOLOGISTS have divided the past periods of man's development into the Stone Age, the Bronze Age, and the Iron Age; and now there has dawned upon mankind the Atomic Age, or as it may be known in the future, the Uranium Age.

There is little doubt but that, within a decade or so, nuclear fission will be one of the chief sources of energy. An ounce of uranium (or of thorium) if subjected to nuclear fission can yield energy estimated to be equivalent to that yielded by the combustion of a ton of coal.

The metal uranium, even when used on a world-wide scale in the peaceful service of man, will not displace but only add to the usefulness of the other metals and the mineral substances which are the tools of industrial civilization. Since the machine age the predominating emphasis on precious metals and gems has shifted to iron, copper, lead, zinc, industrial diamonds, and now to uranium.

Although iron in its many forms is still the most extensively used metal, the outstanding fact in modern industry since the beginning of the twentieth century is the wide and increasing utilization of many 'new' metals, and of natural substances that formerly were regarded almost as scientific curiosities. Indeed, so great and rapid has been the exploitation of minerals that more of them have been extracted from the earth during the past forty years than in all preceding history.

All the metals and most of the materials which are of service to man, other than to provide him with food and clothing, are obtained from the earth's crust, mainly in the

form of minerals. The general public has hitherto taken little interest in minerals, largely because facts concerning them have been confined to scientific and technical literature written in terms unfamiliar to the general reader.

Even governments, including that of our own country, became really interested only during emergencies when there was shortage of supply of minerals needed for essential industries, for in normal times the demand was met as the result of the activities of mining engineers and geologists.

What is a mineral? It has been defined as 'an inorganic substance of definite chemical composition'. This is not a comprehensive definition, for some minerals vary somewhat in their chemical composition, and a few are of organic, not inorganic, origin. The fact is that it is not possible to give a simple and perfect definition of a mineral, for the good reason that in nature there are few sharp lines of demarcation. The geologist, however, like the child who easily recognizes his toys without being able to define them, has a pretty clear conception of what is implied by the term mineral.

Rock is sometimes defined simply as 'an aggregate of minerals', but that again would not satisfy the geologist, for some rocks, like certain limestones, are composed almost entirely of one mineral; and as a geological concept, rock is 'any formation of natural origin that constitutes an integral part of the lithosphere . . .' Clay and loose sand, it may be added, are to the geologist as truly rock as are the hardest of slates, sandstones, granites and so forth.

This book is not concerned, however, with tiresome definitions. Nevertheless, the reader should receive some guidance to enable him to understand in outline the use of some of the terms employed in the context, particularly those referring to the types of igneous rocks with which so

many of the most important industrial minerals are associated.

Because certain rocks were formed by solidification from molten fluids generated within the earth's crust, the geologist refers to them as igneous rocks; to the molten fluids as rock magmas, or simply as magmas. When these rocks have been broken down by natural weathering agencies, and the fragments have been transported by streams to form, for example, beds of clay and of sand which may later have become compacted into shales or sandstones, the deposits, whether consolidated or still in loose form, are known as sedimentary rocks. If in the course of time the shales and sandstones have been converted by intense pressure or temperature conditions into slates, or phyllites, schists or quartzites, they are stated to have been metamorphosed into metamorphic rocks. Thus there are three main classes of rocks: (1) igneous rocks, which are the original sources of almost all rocks; (2) sedimentary rocks, deposited mainly by water; and (3) metamorphic rocks, formed by the subsequent alteration of the igneous and the sedimentary rocks.

Granite is an igneous rock; and, as it contains free or uncombined silica in the form of quartz, it is an *acid* igneous rock. Gabbro is also an igneous rock, and, although it contains silica in combination with other elements, there was not enough silica present in the magma for any of it to crystallize out as free silica, and hence, because of its marked deficiency in silica, gabbro is referred to as a *basic* igneous rock. Between the acid and basic rocks come the intermediate igneous rocks.

When a mineral is stated to be genetically associated with acid igneous rocks, or to have been formed by mineralizing solutions emanating from an acid magma, what is meant is that the materials of which the mineral is mainly composed came originally from the type of rock fluid which, when



## MINERALS IN INDUSTRY

consolidated, would form rocks of the granite family. This family includes numerous types of rocks, such as granites, pegmatites and associated quartz veins, quartz porphyries or 'elvans' as they are called in Cornwall, and many others.

Two examples of mineral occurrences will show clearly the importance of knowing the conditions under which minerals are formed. All the world's tin is obtained from ore-bodies that were formed originally in or in the near neighbourhood of rocks of the granite family, and the mineralizing agents which deposited the tin minerals came from an acid igneous magma. On the other hand, all the important ore-bodies which yield the world's supply of chromium occur in intimate association with very basic, or ultrabasic, igneous rocks; and the mineralizing solutions which deposited the mineral, chromite, emanated from a very basic igneous magma.

It would be contrary to the laws of nature to find workable tin deposits *genetically* associated with basic rocks, and the geologist and mining engineer would waste no time searching for them in an area where acid igneous rocks were absent, for they would know that the geological environment was unsuitable for tin mineralization. There is still much to learn about the mode of occurrence of minerals, but a great deal is known, and in recent years the important discoveries of new mineral resources, and the considerable extension laterally and in depth of those formerly worked on a small scale, are mainly the result of investigations along scientific lines.

There are many ways in which mineral deposits of economic importance have been formed. Some originate by direct concentration from the magma while it is consolidating. Certain heavy minerals, like magnetite, chromite, and ilmenite, crystallize at an early stage from the magma, and may then form segregations by gravity sinking or as the

result of other factors.

The magma may be rich in aluminium and poor in silica, thus giving rise under certain circumstances to the formation of a rock with a high content of corundum. With a different magma and under other conditions, diamond or platinum may be present in the resulting rock.

Mineralizing gases and fluids escape from some magmas and carry with them many kinds of metals in combination with other elements. When the gases and fluids reach a cooler environment, and in some cases come into contact with descending waters, they deposit their burden in the form of minerals containing tin, tungsten, copper, lead, silver, zinc, gold and numerous other metals. Some of these minerals are formed under high temperature and pressure, or hypothermal, conditions; others under relatively low temperatures and pressures, or epithermal conditions; and some under intermediate, or mesothermal conditions.

Waters circulating below the surface can dissolve pre-existing minerals scattered through the rocks, and re-deposit them within fissures; or they can dissolve a rock like limestone and replace it with concentrations of iron or manganese or other minerals.

Surface waters can transport mechanically minerals like those of tin, platinum and gold from weathered metaliferous areas and, by virtue of the chemical stability and high density of these minerals, they may become concentrated as workable alluvial, or placer, deposits.

Other minerals are concentrated from solutions resulting from the decomposition of already existing minerals by acidic or other waters. Sea water contains many elements, and, as the result of the evaporation of waters in enclosed sea-basins in past geological times, valuable saline deposits, attaining in some cases a thickness of thousands of feet and containing potassium, magnesium and other important

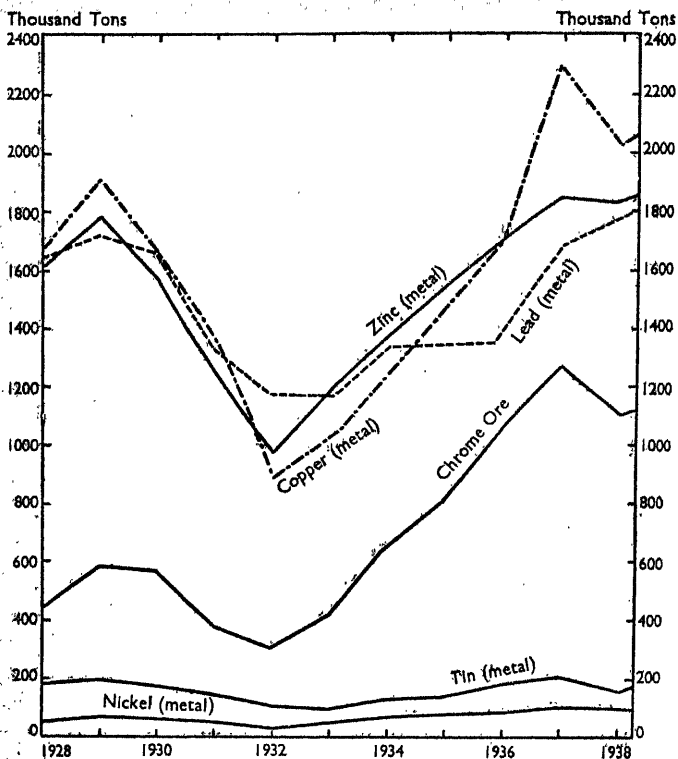


Fig. 1 (a). World Production of Copper, Lead, Zinc, Chromium, Nickel, and Tin during 1928-38. Their world production for 1948 to 1952 is shown in Fig. 1 (b), page 21

salts, have been formed.

These are some of the chief processes by which mineral deposits of commercial importance have been formed, and others are described to account for the natural history of the particular mineral under consideration.

Some minerals, although of comparatively rare occurrence, have an importance out of all proportion to the

amount consumed. Radio-active minerals exemplify this remarkably well, but there are many others which occupy a key position, for the reason that very small amounts of the metals or non-metals which they yield have a profound effect when added to other metals. For example, less than one per cent of vanadium suffices to impart beneficial properties to steel, rendering it suitable for uses involving strain; and by alloying the soft metal, lead, with as little as one-twentieth of one per cent of tellurium, the lead offers increased resistance to frost when employed for water-pipes.

Possibly no other metal during the last three decades, used in equal amount for any purpose, has been of greater service to man than tungsten in the form of filament for electric bulbs. Less than two tons of tungsten metal is required to supply filaments for 100 million electric lamps, and the total annual world consumption of the metal for light filament is little more than 100 tons. The saving effected by the substitution for the old carbon filament of tungsten filament, which is four and a half times as efficient, is stated to be many hundreds of millions of pounds.

Minerals like vermiculite, nepheline, those of the sillimanite group, and others which were almost unknown twenty-five years ago outside geological circles, are now finding extensive utilization in industry, and their number is continually increasing. Almost all the minerals now employed in the service of man, other than coal and petroleum and other fuels, are referred to in this book, and an endeavour has been made to include the most recent uses of the products which they yield.

During the Second World War the production of certain minerals essential for war purposes was increased ten-fold and more; mineralized areas that normally would not have been worked on a large scale were exploited intensively because their products could be transported to consuming

centres without enemy interference; and in some of the world's chief mineral-producing centres in pre-war days, mining operations virtually ceased owing to enemy action.

For the first few years after the war, political and financial difficulties hindered the return to normal conditions so that the production figures for various countries were misleading as to their mineral potentialities, even more misleading than was conveyed by mere statistics, for official returns from countries composing the Eastern Powers were (and still are) not available for many raw materials.

The maps showing the world distribution of minerals, and the diagrams illustrating their relative production in various countries, were drawn specially for incorporation in this book. The quinquennial period, 1934-8, was chosen for average pre-war production figures for two reasons: reliable statistics for that period were, in most cases, available; and they represented the state of the mineral industry under more or less normal conditions. Later figures, when obtainable and reliable, are given in the context, but spectacular increases or decreases from the quinquennial averages are, in almost all instances, the result of abnormal conditions during and after the Second World War.

Even in normal, or almost normal, times there is a change – generally a gradual change – in the production of minerals in different countries from year to year. During war, or the probability of a war, it is not uncommon for fluctuations of a spectacular nature to occur. For example, between 1943 and 1945 the production of bauxite in the U.S.A. *decreased* from six million tons to under one million, and that of copper ore from one million to 600,000 tons. From 1938 to 1942 the U.S.A. production of iron ore *increased* four-fold from 28 million to over 100 million tons. Great fluctuations were common also in other countries.

It is thus clear that the average production over a period

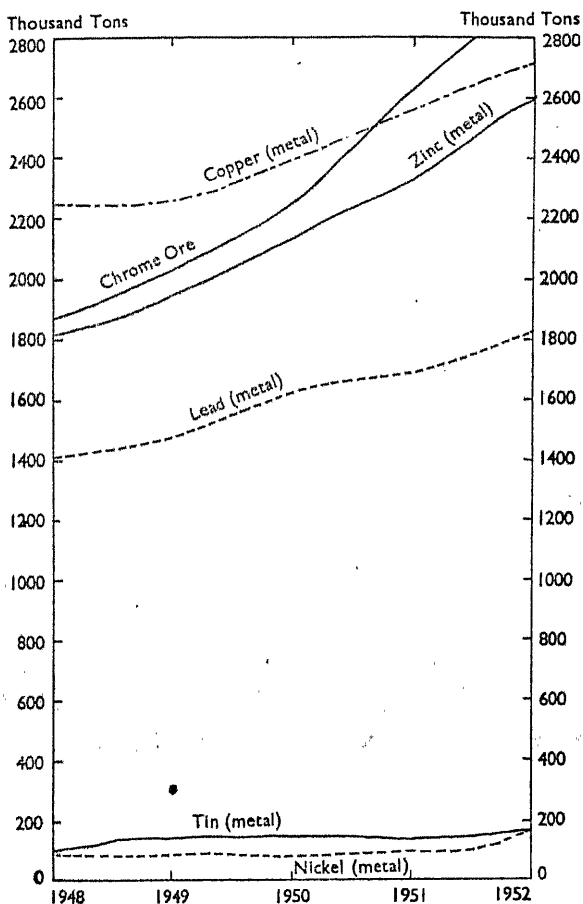


Fig. 1 (b). World Production of Copper, Lead, Zinc, Chromium, Nickel, and Tin during 1948-52

of years gives the more faithful conception of the state of the mineral industry in different parts of the world. For this reason the average figures for the quinquennial period

1948-52 are given in the context for every mineral for which the figures were available.

Even in normal pre-war years there was a lag of at least two years between the availability of reasonably reliable annual statistics of world mineral production, and since the war the lag has increased considerably for some countries. Moreover, the statistics for certain minerals in the U.S.S.R. and in certain adjacent countries have not been available for some years on this side of the Iron Curtain.

The mineral industry has become the keystone of military security and the supply of minerals occupies a position of foremost priority in the plans of the chief nations.

# MINERALS IN INDUSTRY

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## ABRASIVES

FROM earliest times hard substances as they occur in nature, or after crushing or powdering, have been used as abrasives. In late years several artificial abrasives have been manufactured, and for certain purposes some of these have proved superior to the natural substances; but in the case of the hardest and highest-grade abrasive of all, diamond, nature still remains supreme.

The most successful and widely-used artificial abrasive is carborundum, made by fusion in the electric furnace of a mixture of the cheap and plentiful materials, silica, coke and sawdust, the reaction being  $\text{SiO}_2 + 3\text{C} = \text{CSi} + 2\text{CO}$ . Another useful one is artificial corundum, made by fusing the mineral bauxite in the electric furnace. The product is marketed as grain, powder, or in special shapes, under trade names such as Alundum, Aloxite, Caralox, Exolon and Lionite. The hardest of all artificial abrasives is the recently discovered boron carbide, made from a mixture of borax and coke. If we regard quartz (which easily scratches steel) as having a hardness of 7 (as in Mohs' scale of hardness), it is estimated that boron carbide would have a hardness of about 20 and the various types of diamond a hardness of from 36 to 42.

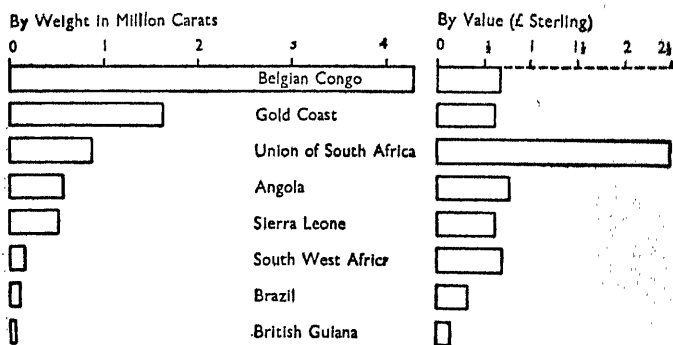
The chief high-grade natural abrasives, in order of their hardness, are the minerals diamond, corundum, emery, and garnet. Rocks like certain types of sandstone and grit are extensively used in the form of grindstones, pulpstones, sharpening stones, hones and scouring powders. Pumice and



tripolite (see under diatomite) are also widely used as abrasives.

Most of the world's production of diamonds during recent years has been employed in industry, mainly as cutting or abrasive agent. The black diamond, carbonado, and the badly-coloured diamond, bort, are the two chief types used as abrasives. Carbonado, which comes mainly from Bahia in Brazil, is the toughest and hardest variety, but as against an annual production of about 30,000 carats of

## DIAMONDS



During 1934-8 average annual production 8,055,000 carats  
 " " " " value £6,324,000 sterling

Fig. 2.

carbonado, more than 200 times that amount is produced of bort, which is used extensively as an abrasive dust, especially when bonded in Bakelite wheels; it is also used for die-making, for diamond-set shaping tools, cutting precious stones, and, on account of its lower price, it is superseding carbonado in some diamond drills and in drill bits. Most of the world's bort is obtained from the African fields. The geographical distribution of the chief diamond fields is shown in Fig. 31.

The average annual world production of diamonds for the five years ended in 1952 was 15,058,400 metric carats. The average annual production of the chief producing countries for this quinquennial period was: Belgian Congo, 9,559,117 carats; Union of South Africa, 1,798,150; Gold Coast, 1,321,028; Angola, 716,397; Sierra Leone, 508,548; South-West Africa, 405,246; Brazil, 250,000; Tanganyika, 152,289 carats.

No mineral is under a more rigid market control than the diamond.

CORUNDUM,  $\text{Al}_2\text{O}_3$ , is second only to diamond among minerals in hardness. The common variety used for abrasive purposes is non-transparent, usually dull grey to brown in colour, occurring in crystals which are six-sided prisms, often tapering at both ends to a barrel-shaped form.

The gem varieties of corundum, sapphire and ruby, are transparent and of beautiful colour, such as the blue sapphire and the 'pigeon blood' red of the ruby.

Corundum often crystallizes direct from magma rich in alumina and poor in silica, as in the nepheline syenites of certain parts of Ontario, which were formerly among the most important producers of the mineral, but between 1921 and 1940 there was virtually no Canadian production. During the decade ended in 1940, practically the whole of the world's supply of corundum, about 3,000 tons annually, came from north-eastern Transvaal from veins and their weathered outcrops. Most of the material was exported to U.S.A. for use in grinding wheels, etc.

The chief corundum-producing countries in 1952, in order of their importance, were: Union of South Africa, 3,731 long tons; India, 637; Australia, 54; Nyasaland, 46 tons.

EMERY is essentially an intimate mixture of granular corundum and magnetite, and in powdered form has long been used as emery paper, emery cloth and emery wheels. The presence of magnetite, and often of hematite, is advantageous for some purposes where a less harsh abrasive than corundum is required.

Deposits of emery usually occur as lenses or pockets in crystalline limestone, or as residual deposits after the removal by weathering of such rocks. The main producing fields in order of importance are the island of Naxos in the Grecian Archipelago, the Province of Aiden in Asia Minor, and the Central Urals in the U.S.S.R. Naxos emery, owing to the hardness and sharpness of the grains and their resistance to heat, is the most suitable for grinding wheels, the Turkish emery being used mostly for emery paper and cloth and polishing wheels. In 1952, the U.S.A. produced 9,243 long tons of emery; Turkey, 8,110; Greece, 6,000 tons. The geographical distribution of the chief emery fields is shown in Fig. 31.

GARNETS are of different kinds, but those used for abrasive purposes are all iron garnets, the variety almandine,  $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$ , being the commonest. Although garnet is a frequent constituent in many gneisses and schists throughout the world, it seldom occurs in these rocks in sufficient concentration to be workable. The only important commercial deposits of abrasive garnet are those of the Adirondacks in the U.S.A., where 70% of the rock may be garnet and where crystals several feet in diameter are not uncommon. During the decade 1930-9 these deposits yielded more than 3,000 tons annually, principally for use in the manufacture of abrasive-coated paper and cloth. In 1952 the U.S.A. output of abrasive garnet had increased to 10,170 long tons.

The world production of pumice during 1952 was

approximately 750,000 long tons, of which the U.S.A. yielded 670,000 tons; Italy about 100,000; France and Greece about 10,000 each.

## ALUMINIUM AND BAUXITE

SEVENTY years ago no process was known by which aluminium could be produced commercially. The metal was then regarded as a scientific curiosity, although, next to oxygen and silicon, it is the third most abundant element in the earth's crust, iron being fourth, but well behind aluminium. Yet iron was produced commercially hundreds of years before metallic aluminium was even known! There are two reasons for this. Iron oxide occurs in nature in a form in which it can be put directly in the furnace, whereas the oxide of aluminium is impure and has to undergo a complex and expensive process before it can be reduced to metal. The second reason is that coal or coke can take away the oxygen from iron oxide, but not from aluminium oxide. In fact, the first method by which aluminium oxide was reduced to metal was by employing sodium metal as the reducing agent. But in 1886 C. W. Hall, a young student twenty-two years of age, found that when aluminium oxide was dissolved in a fused bath of cryolite, and subjected to electrolysis, the metal could be produced. It takes, however, about 25,000 kilowatt-hours of electric energy to produce a ton of aluminium, or the equivalent of about twenty times more coal than is consumed for a ton of iron. Thus it is that plentiful and cheap electric power is a first consideration in locating aluminium plants, and some of the largest are where electricity is generated on a large scale by water-power.

When some fifty-five years ago the metal became avail-

able at a reasonable price and in appreciable quantities, the claims made for it proved far too optimistic, and the public was greatly disappointed with the domestic articles supplied. These were found to corrode and flake badly, owing to the impurities left in the metal. Also, the unalloyed metal was found to be too soft for most purposes.

Later, metallurgists found it possible to harden the metal, and now aluminium alloys can be made as strong as steel at one-third its weight.

The distinctive physical properties that account for the spectacular expansion in recent years of the use of aluminium are its lightness, high strength compared with its weight, resistance to corrosion, and its relatively high electrical conductivity. Half a century ago the production was a matter of lb., not tons; in 1918 it had risen to close on 150,000 long tons; in 1937 to nearly half a million and in 1941 to almost a million tons. For the five years ended in 1952 the world production was 1,240,000; 1,284,000; 1,466,000; 1,781,000 and 2,065,000 long tons, respectively.

The rapid expansion of aluminium production in Canada to meet war needs gave a maximum of 496,000 tons of the metal in 1943, which represents a ten-fold increase in six years. In 1952 the U.S.A. production was 836,902 long tons; Canada, 442,878; U.S.S.R., 295,000; France 104,452.

Aluminium is used as the pure metal and as an alloy in castings and forgings, as well as rolled, pressed, spun, drawn, and stamped. A simple duralumin alloy contains about 4% copper, less than 1% each of magnesium and manganese, and the remainder of aluminium.

The chief consumption is in railway, road and air transport. Railways consume more aluminium year by year in the construction of coaches, goods wagons and interior fittings. In the automobile industry it is used in body and engine construction, and its critical importance in the

manufacture of aircraft is known to everyone.

The metal is now a serious competitor of copper in the construction of long-distance electric transmission lines. Its lower weight permits reduction in the number of supporting towers, and its relative cheapness is a factor of considerable economy in construction. In 1939 electrical conductors consumed more aluminium in the U.S.A. than any industry other than transport. During World War II, aluminium foil played an important role in electronic war, as an instrument of 'counterradar' to frustrate German radar detection. For advanced airfields portable aluminium landing mats, half the weight of steel mats, were used.

New uses are constantly being developed for the metal in the chemical, electrical and engineering trades, for domestic ware and fittings, in shipbuilding and for numerous other purposes. It is fortunate that aluminium, unlike most tin that passes into industry, is easily recoverable as scrap and can be used again.

## BAUXITE

### *Occurrence and Production*

Almost all the aluminium of commerce is obtained from one mineral, bauxite, the hydrated oxide of aluminium,  $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ . It is claylike, adheres to the tongue, and varies in colour from dirty white to greyish, and when iron is present to yellow, brown and reddish brown, and may be mottled.

Other aluminium minerals are being used to a limited extent, such as leucite in Italy, and nepheline in the U.S.S.R.; experiments are in progress for the recovery of the metal from andalusite in Sweden, alunite in the U.S.A. and the U.S.S.R., corundum in Sweden, lignite ashes in the

U.S.S.R., and attempts were made in this country for its extraction from china-clay. There is little doubt that in the future bauxite will not retain its present virtual monopoly as the raw material for aluminium.

Of the non-metallic uses of bauxite the most important are for the manufacture of abrasives, refractories, chemicals and to a lesser degree a high-alumina cement characterized by rapid hardening and resistance to chemical action and heat. Bauxite abrasives, made by fusing bauxite or alumina in electric furnaces, are marketed under various trade names, such as Alundum, Aloxite, etc. High-alumina refractories, such as bauxite bricks, are being increasingly employed under severe furnace conditions. The chief commercial salts of aluminium produced from bauxite are the sulphate, hydroxide, chloride and complex sulphates (alums), which are used mainly in paper-making, dyeing, tanning, water purification, decolorizing and deodorizing of mineral oils and other minor uses.

Bauxite deposits were formed on or near the earth's surface by the decomposition, under moist tropical or sub-tropical conditions, of clays and clayey limestones and of igneous rocks high in aluminium silicates. The aluminium silicates present in these rocks (clay is a rock to the geologist) were decomposed under favourable atmospheric influences, and bacteria probably played an important part in the concentration of the alumina. The fact that large deposits of bauxite occur in temperate regions in the U.S.A., France, Hungary and northern Russia is considered by geologists as evidence, additional to other factors, of the prevalence in earlier geological periods of tropical or sub-tropical climates in those regions.

Horizontal or gently tilted sheets or blankets of bauxite are sometimes found as cappings on extensive plateaux or on flat-topped hills which have been levelled by prolonged

erosion. The upper part of these deposits is usually hardened by the cementing effect of iron oxide, and the bauxite commonly has a concretionary (pisolitic) structure. Below the surface it becomes softer, and at greater depth may pass somewhat abruptly into the underlying residual clay.

Bauxite beds which are now covered by sedimentary or igneous rocks usually represent ancient surface deposits

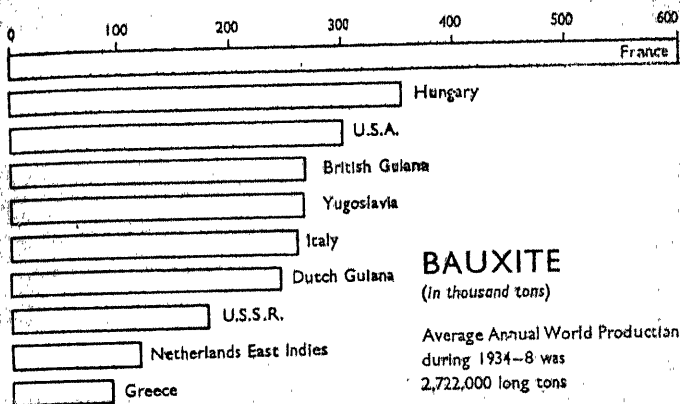


Fig. 3.

which have subsequently been overlaid by younger rocks. Irregular masses, pipes or pockets of bauxite frequently occur in limestone. Some represent the solution and removal of the limestone with the resulting segregation of the clayey material under tropical conditions, and many of the pockets were formed by the transport of that material into sink-holes and solution caverns. A few detrital deposits of bauxite are known which are probably of sedimentary origin resulting from the mechanical concentration of bauxite fragments from pre-existing laterites which had been swept out to sea by the normal processes of erosion.

A notable feature of most bauxite deposits is their close



association with old land surfaces. Thus it is that in the older rocks the bauxite occurs along unconformities representing long periods during which laterization was effected. Bauxite deposits of comparatively recent age, such as those of British and Dutch Guiana, of the Gold Coast, and of India, lie on almost level surfaces which have long remained undisturbed under tropical conditions.

For a score of years France was the world's leading producer of bauxite, which is named after Les Baux in the south of France, where it was discovered in 1821. The deposits occur as pockets, lenses or interlayered beds in Cretaceous limestone. Until 1936 the U.S.A. held second place, most of its output being from Arkansas. Since 1937 the output of bauxite has increased in most of the producing countries, with especially rapid expansion in Dutch and British Guiana, now the two foremost producing countries.

The chief countries, in order of importance of their average annual production for the five years ended in 1952, were: Dutch Guiana 2,407,800 tons; British Guiana, 1,971,700; U.S.A., 1,490,240; France, 912,570; U.S.S.R., 720,000; Indonesia, 518,317; Hungary, 406,000; Yugoslavia, 337,360. The world production for the five years ended in 1952 averaged 9,382,000 annually.

Although Germany's domestic supply of the raw material for the quinquennial period 1934-8 was only  $\frac{1}{4}\%$  of that of the world, yet it produced more than a quarter of the world's aluminium over that period, and was thus easily the chief producer of the metal.

Canada is now second only to the U.S.A. as the largest aluminium-producing country, using bauxite mainly from British Guiana, whereas practically all the Dutch Guiana supply is shipped to the U.S.A. Great Britain is wholly dependent upon imported bauxite. The geographical distribution of the chief bauxite fields is shown in Fig. 28.

Recent information indicates that Jamaica and Haiti will become large producers in the near future.

## ANTIMONY

EASTERN damsels since early times have used the powdered mineral, stibnite or antimonite, for darkening their eyelids. In recent times about three-fourths of the total annual antimony consumption of some 34,000 long tons has been used to impart hardness and stiffness to various lead alloys. 'Hard lead', containing from 4% to 12% antimony, is widely employed for storage batteries, for lead sheet and lead pipes in the chemical industry, where resistance to sulphuric acid is of consequence, for sheathed telegraph and telephone cables, and as a covering for fuses. Small percentages of antimony are added to lead used for collapsible tubes, sheet and foil.

War stimulates greatly the demand for antimony, especially for hardening shrapnel balls and bullet cores of lead. Moreover, the antimony sulphide in shrapnel shells produces, on explosion of the charge, a dense white smoke helpful in locating the point of burst. The trichloride is used as a bronzing solution for gun barrels, and antimony oxide as a canvas-fireproofing spray and as an ingredient of non-inflammable paint, especially for naval and cargo ships. Antimony sulphide was used in large quantities for the dark pigment in camouflage paint because it has the same infra-red reflectance properties as the surrounding green foliage.

Antimony in combination with one or more other metals such as lead, tin and copper, forms many useful alloys, such as the anti-friction alloy, Babbitt metal, with about 83%

tin, 11% antimony and 6% copper, although some babbitt is now made without antimony. Type-metal is essentially a lead-antimony alloy, but usually with a small percentage of tin, and occasionally of copper. The antimony present increases the fusibility and hardness of the lead, and gives to the alloy the property of slight expansion on solidification, thus making possible rapid casting of well-formed letters in type-setting machines. Linotype and monotype metal contain 10% to 15% antimony, but for the thinner stereotype plates requiring greater stiffness as much as 23% is used. The so-called white metal alloys contain varying amounts of antimony. One of the chief, Britannia metal, an alloy of lead, antimony and copper, is employed for making spoons, dish-covers and other hollow-ware for table use. Pewter, once a favourite for church and for public-house vessels, is a lead-tin-antimony alloy.

Antimony as the pure metal has very limited applications, and even those are more for ornamental than practical purposes, such as oriental bric-a-brac. Compounds of the metal, however, have several uses. Antimony oxides are employed to a considerable extent as paint pigments, fusible enamels, and as colouring agents in glass. The sulphide of antimony is now less used than formerly for vulcanizing rubber and for giving it a characteristic red colour. Safety matches have about 3% of the sulphide in the match head and about 8% in the striking surface of the match box.

### *Occurrence and Production*

The chief source of antimony is the ore mineral, stibnite,  $\text{Sb}_2\text{S}_3$ , less commonly known as antimonite. In the most important of the Hunan deposits of China and those of Bolivia, the stibnite is practically unweathered, but in many of the deposits of southern China, of Mexico and

Algeria, the original stibnite has been changed to insoluble white or yellowish oxides of antimony, such as cervantite,  $\text{Sb}_2\text{O}_4$ , senarmontite,  $\text{Sb}_2\text{O}_3$ , and valentinite,  $\text{Sb}_2\text{O}_3$ .

Most antimony ores of economic importance have been formed under intermediate or comparatively low temperature and pressure conditions at no great depth below the original surface, but stibnite occurs also in quartz veins of deep-seated origin in or near intrusive igneous rocks like the granites. Such quartz veins may carry workable amounts

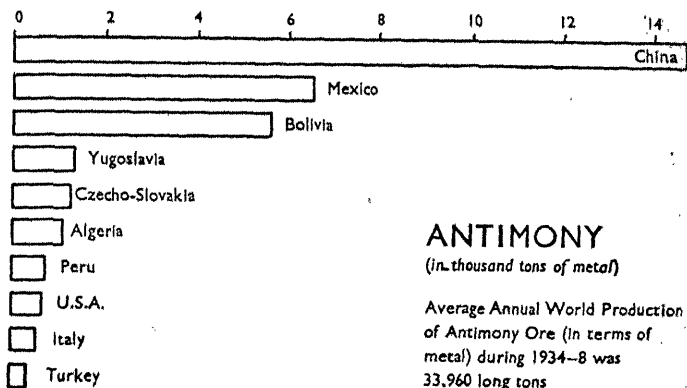


Fig. 4.

of gold. Another type of occurrence is as replacement deposits in limestones and shales, usually with galena. The best crystals of stibnite displayed in most geological museums are from small Japanese deposits formed under low temperature conditions.

Between 1913 and 1939 China produced 60% of the world's output of antimony, principally from quartz-stibnite veins traversing Palaeozoic quartzites near Changsha in Hunan province. Since the Japanese invasion of China and the consequent decrease in Chinese production,

the outputs from Bolivia and Mexico have increased greatly and in 1939 surpassed those of China. During the five years ended in 1952, the average annual production of the chief producing countries, in terms of the metal, was: Bolivia, 10,418 long tons; Union of South Africa, 7,827; Mexico, 6,173; China, 5,840; Czechoslovakia, 3000; U.S.A., 2,910. The world average annual production for this quinquennial period was 46,720 tons. The geographical distribution of the chief antimony fields is shown in Fig. 28.

The ore as mined may be low-grade and often subjected to liquation, the easily melted stibnite being allowed to drain away from the gangue or waste rock.

The terms applied to antimony products are confusing to the uninitiated. Antimony metal is sometimes still referred to by the ancient name 'regulus', whereas 'crude antimony' or 'needle antimony' or simply 'crude' do not refer to the crude ore but to the liquated antimony sulphide containing about 70% of metal and occasionally known as 'antimony matte'. The purest grade of refined antimony is usually termed 'star antimony' owing to the characteristic spangled markings on the surface of the ingots.

## ARSENIC

ARSENIC is best known to the public as a killer of weeds, insects and, in certain sensational cases, of an unwanted husband or wife. The chief consumption of arsenic is as an insecticide for boll weevils and potato bugs, which accounts in the main for the 68% or so of the total world production of arsenic used as insecticides and germicides. Arsenic in the form of lead arsenate is used for exterminating boll weevils on cotton, and copper arsenite for the potato bug. Compounds of arsenic form essential ingredients in sheep and cattle dip, in certain wood preservatives, in some paints and in preparations for preserving animal hides.

Close on 20% of the yearly consumption of arsenic is employed in making weed-killers and about 3% in glass manufacture. White arsenic, which is the oxide of arsenic, acts as an oxidizing agent in glass-making and removes the unpleasant greenish tint produced by iron oxide. It is also utilized in calico-printing, in the fixation of aniline dyes and in many medical preparations, such as Fowler's solution (potassium arsenite) and Ehrlich's famous '606'.

Very little use is made of arsenic in metallic form. About 0.4% of the metal added to molten lead yields harder lead shot, and facilitates also the formation of truly spherical pellets when the melt is poured down the shot-tower. Electro-deposition of arsenic on brass gives a dark oxidized finish. Recently the metal has been introduced into certain bearing-metal alloys and wiping solder, and arsenical copper has been found to increase corrosion resistance.

### *Occurrence and Production*

Almost all the world's arsenic is obtained as a by-product in the flue dust of smelters treating arsenical ores for the recovery of the gold, copper, or other metals that may be present. The flue dust is in the form of soot, and consists mainly of the oxide of arsenic  $\text{As}_2\text{O}_3$ , which, after purification, is marketed in the form of a white powder.

Arsenopyrite, also called mispickel and arsenical pyrites, is the most abundant ore mineral, frequently proving a great nuisance in gold, copper, tin, tungsten, lead, zinc and other mines. More spectacular in appearance than the steel-grey arsenopyrite, but less common, are the orange-red sulphide, realgar,  $\text{AsS}$ , and the yellow-lemon orpiment,  $\text{As}_2\text{S}_3$ , two minerals used as pigments in lacquer work and for other purposes. Arsenic enters into the composition of numerous complex sulphides, such as the copper mineral, enargite, and the silver mineral, proustite.

It also occurs in nature in metallic form as a minor constituent of certain lead, silver, nickel and cobalt ores.

The mine that produces most arsenic in the world is at Boliden on the Baltic shore of northern Sweden, where one of the largest of all known ore-bodies was discovered by electrical prospecting twenty-five years ago. It is about 2,000 feet long and 60 feet wide, is a rich sulphide deposit carrying approximately  $\text{£}2\frac{3}{4}$  of gold and  $2\frac{1}{4}$  ounces of silver per ton with  $2\frac{1}{4}\%$  copper, 10% arsenic and 30% sulphur. This one mine could supply the world for a long period of years with all the arsenic it consumes. Only a small fraction of its output is refined and marketed, the remainder being stored. Other notable gold mines which produce arsenic as a by-product are Wiluna in Western Australia, St John del Rey and Passagem in Brazil, and mines in Hastings County, Ontario. Most of the white arsenic obtained from domestic ores in the U.S.A. is a by-product of copper and lead smelting, as at Butte in Montana and Tintic in Utah.

In 1952 the U.S.A. produced 13,994 long tons of arsenic (white arsenic); France, 4,000; Mexico, 2,820; Italy, 2,110; Japan, 1,552 tons. Portugal, Belgium and Sweden were also large producers.

## ASBESTOS

THE fire-resistant property and fibrous texture of asbestos have attracted attention throughout the ages. Plutarch refers to the 'perpetual' lamp-wicks used by Vestal Virgins, and the ancients to 'amianthus, undefiled', in allusion to the ease with which asbestos cloth could be cleaned by putting it on the fire.

As now used commercially, the term 'asbestos' is applied not to a single mineral but to a group of minerals which can be separated easily into fibres, can be spun or woven into

fabrics, and which have varying degrees of resistance to heat. Originally, however, it was applied to a variety of amphibole named actinolite, which has now but little economic importance.

The remarkable combination of physical properties which make asbestos of such great industrial value include its incombustibility, infusibility, fibrous structure, strength and flexibility of the fibres, low heat-conductivity, high electrical resistance, inertness to chemical action, and freedom from decay. Some varieties of asbestos possess certain of these properties to a higher degree than others, and hence the different kinds have their special fields of usefulness. Many of these properties were unknown to the ancients, and it was not until 1865 that the first serious attempt was made, by a London syndicate, to develop asbestos deposits in the Aosta Valley of the Italian Alps. Not until the beginning of the present century did the mineral become extensively used in industry.

The infusibility of asbestos finds a wide range of uses in fireproof materials, including roofing shingles, mill-board, flat and corrugated sheets, asbestos paper, fireproof paints, roofing cements and tiles, and packing. For many of these the short-fibre asbestos is admirable, but the long-fibred mineral (fibres over a quarter of an inch in length) which can be spun and woven into textiles and cloth is employed for fireman's rope and clothes, helmets, sheets, and theatre safety curtains. In brake-linings and clutch facings the asbestos is usually reinforced with wire threads.

Its low electrical conductivity enables it to serve as insulating material on cables and wires, switchboards and other electrical apparatus; and the acid-resisting qualities of some varieties of asbestos render them particularly suitable for the filtering of acids. The greatest consumption is undoubtedly in the manufacture of asbestos-cement



products such as roofing tiles and sheets. Asbestos fabrics reinforced with glass fibre, and asbestos reinforced with plastics, are among its recent new uses.

### *Varieties, Occurrence and Production*

The six varieties of asbestos fall into two mineral groups: (1) chrysotile, or serpentine asbestos, and (2) amphibole asbestos, including anthophyllite, amosite, crocidolite, tremolite and actinolite. The term 'anthophyllite' is used by some to include all the four forms of amphibole asbestos, since it is the commonest species in that group.

About 90% of the world's production consists of chrysotile asbestos, a hydrated magnesium silicate. Its fibres are short, usually from one-sixteenth to one-half inch long, and rarely exceeding 6 inches. The mineral is readily separated into extremely fine, flexible fibres and the better grades have a pleasing silky lustre and high tensile strength. Tests have shown that fibres only 0.03 inch thick can support an average weight of about 15 lb., and it is stated that a thread of it can be spun so fine that 6 miles of it would weigh only a pound! It generally occurs as cross-fibres within well-defined veinlets traversing serpentine. Its origin is controversial. Many authorities believe that the fibres were formed under the action of hydrothermal waters which were circulating within the serpentine *before* the magma solidified, while others suggest that the chrysotile resulted from emanations from an acid igneous rock, such as granite, *after* the consolidation of the serpentine rock.

Although chrysotile is susceptible to attack even by weak acids and by sea-water, the fineness, strength, flexibility and spinability of its fibre make it the most valuable variety of asbestos. Most of the world's chrysotile comes from two regions, the Thetford district of Quebec in Canada and the Bazhenov field in the Central Urals, U.S.S.R. These two

countries produced more than 75% of the total world supply of asbestos during 1934-8, while Southern Rhodesia for the same period yielded, in the form of chrysotile, 10% of the world total.

Anthophyllite is typically found as mass fibre, the grey or greenish-grey fibres being arranged in radiating aggregates or bunched together irregularly. Usually the fibre is somewhat brittle, of relatively low tensile strength, and only rarely of spinning quality. It is utilized mainly in cements and plasters, in paint and as insulating material.

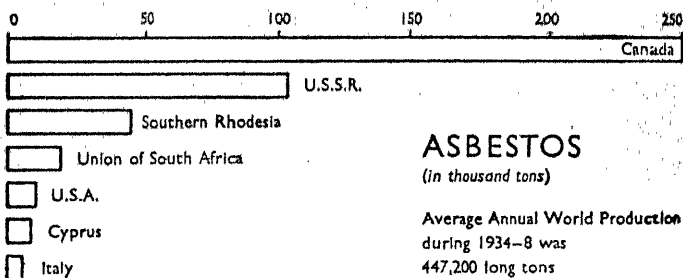


Fig. 5.

Amosite is an iron-rich form of anthophyllite which occurs in economic quantities only in the Union of South Africa, and in fact its name is derived from the initial letters of 'Asbestos Mine of South Africa', the title of the mine where it was first worked. The mineral is characterized by unusually long fibres, which average about 8 inches and may reach 11 inches in length, but the harshness and poor spinning qualities of the fibres limit its main uses to heat-insulating blocks, binders, and to appliances where its resistance to attack by acids makes it preferable to chrysotile.

Crocidolite is a sodium-bearing amphibole, known also

as 'blue asbestos', in allusion to its prevalent colour, and as 'Cape Blue' because formerly it was mined only in Cape Province, South Africa, where it occurs as cross-fibre in narrow seams interbedded with banded jaspers and sedimentary ironstones. The fibres are commonly about an inch long, and although not so infusible or so easily spun as those of chrysotile, they are stronger and more resistant to chemical action. When hardened as the result of silicification it has a limited use as an ornamental stone, such as is used for umbrella handles and sticks and so forth, under the name of 'cat's eye'. If the replacement of the asbestos by silica was accompanied by oxidation to a golden-brown colour it is often referred to as 'tiger's eye'.

Tremolite asbestos, known also as Italian asbestos, is white when pure, and occasionally forms long fibres exceeding a yard in length. Its low tensile strength and brittleness make it unsuitable for use in textiles, but it is frequently employed in wall insulation and boiler lagging, and its acid-resisting properties render it especially suitable for acid-filtering processes. Actinolite is seldom used on a commercial scale, and then only when ground and mixed with other varieties of asbestos. Both tremolite and actinolite usually occur in metamorphic rocks such as talc schists and mica schists, with the fibres mostly orientated along the foliation planes of the enclosing rock.

The average annual world production of asbestos for the five years ended in 1952 was 1,005,200 long tons; and the average annual production during that period of the chief production countries was: Canada, 726,706 tons; Union of South Africa, 70,500; Southern Rhodesia, 68,280; U.S.A., 40,560; Swaziland, 30,143.

Fig. 5 shows the yield of asbestos in the chief producing countries in normal times before World War II, and Fig. 28 the geographical distribution of the chief fields.

## BARIUM

PEOPLE about to be X-rayed may have to drink quantities of a mixture composed of barium sulphate stirred up in milk to form a coating on the walls of the stomach and intestines and thus make them visible under the impact of the X-rays. That is one of the cases where barium compounds are not substitutes for other substances.

Barium is little known to the general public, because the name of the element does not occur in the compounds of barium most used in industry nor in the minerals from which the compounds are derived. The two chief barium minerals are the sulphate, barytes,  $\text{BaSO}_4$ , and the carbonate, witherite,  $\text{BaCO}_3$ . Barytes, known as barite in the U.S.A., is commercially by far the more important of the two minerals.

The greatest single use of barium is in the manufacture of white paint pigment, lithopone, an intimate mixture of about 70% barium sulphate and 30% zinc sulphide. Unlike white lead, for which it is a substitute in paint, lithopone is non-poisonous and is not discoloured by sulphurous gases, and the presence of a trace of cobalt or alkali phosphate prevents the lithopone paint from darkening on exposure to sunlight. Lithopone is also employed as a filler in rubber, paper, linoleum and oilcloth.

The mineral, barytes, when ground to various degrees of fineness, serves as an extender in white paints and as a filler in heavy paper and cards, textiles and leather. A recent and increasingly important use of crushed barytes is as a heavy medium in muds which are poured into oil-wells to hold back gas during boring operations until the casings are inserted. For this purpose and for dark-coloured paints the

cheaper 'off-colour' barytes, instead of the more expensive white mineral, is employed.

Barium in the form of metal is used to a limited extent in a number of alloys, for example, in combination with lead and calcium for bearing alloys and with aluminium, magnesium or nickel for radio valves.

Precipitated barium sulphate, or *blanc fixe*, is whiter and finer-grained than the powdered natural barytes or witherite, the two minerals from which it is made. *Blanc fixe* is used largely as a base for coal-tar dyestuffs, as a filler in enamel paints and for coating paper. Small amounts of the carbonate and sulphate of barium increase the fluidity of molten glass, thereby facilitating the manufacture of intricate glassware moulds. Barium peroxide is used in making hydrogen peroxide, barium hydrate for refining beet-sugar, barium nitrate in pyrotechnics and for green flares and signal lights, and barium carbonate for the case-hardening of steels and for rat poison.

Important uses of barium carbonate and barium nitrate during World War II were in making shell primers, incendiary bombs, tracers, and green signal flares.

### *Occurrence and Production*

Barytes is a frequent gangue mineral in certain ore deposits, particularly lead and zinc veins; it also occurs almost alone in veins traversing other rocks, chiefly limestone and dolomite. In Derbyshire and in the north of England, in Germany and the U.S.A., veins of these two types are common, and owe their origin mainly to ascending hot mineralizing solutions, although in very few cases the deposits may have been formed by precipitation from descending waters which have leached out and concentrated the barium from surrounding rocks. Barytes occurs also as residual deposits in clays derived from the weathering

of soluble barium-bearing rocks such as limestones and dolomites, and the principal producing deposits in the U.S.A. are of this type.

Witherite in economic quantities is of rare occurrence, the only workable deposits hitherto recorded being in mines in Durham and Northumberland. Settlingstones mine, west of Hexham in Northumberland, is the most famous witherite mine in the world. The mode of occurrence of the mineral is like that of vein barytes, and the two minerals occur together. There appears to be strong evidence that in this country witherite is a secondary product after barytes.

During the quinquennial period 1934-8 the average annual production of barium minerals was nearly a million long tons, of which Germany produced 42%, the U.S.A. 25%, U.S.S.R. possibly 12% and the United Kingdom nearly 8%.

In 1952, the chief producing countries were: U.S.A. 800,000 long tons of barytes; Germany (Federal) 340,378; Canada, 106,547; Italy, 54,382; Great Britain, 43,311; France, 28,000; Yugoslavia, 26,390; Greece, 21,162; Japan, 14,000; Spain, 13,818 tons. The average annual world production for the five years ended in 1952 was 1,398,000; for 1952 it was 1,500,000 tons.

## BERYLLIUM

**MOST** readers are familiar with two of the beryllium minerals, namely the beautiful grass-green and transparent precious stone, emerald, and the pale greenish-blue gemstone, aquamarine, both of which are varieties of beryl, a silicate of beryllium and aluminium.

It is now accepted among metallurgists that if the metal, beryllium, could be produced in considerable quantities it would rapidly become of great service, for this tin-white

metal is remarkably light in weight, being very slightly heavier than magnesium and having a considerably lower density, 1.85, than aluminium, 2.7. Moreover, the metal possesses other valuable properties, such as strength, hardness and resistance to heat and corrosion, which it imparts to a greater or less degree to its alloys. Unfortunately, however, the source of the metal is restricted to one important mineral, beryl, which seldom occurs in sufficient quantities to be worked on a large scale, and the small production of beryl is obtained mainly as a by-product in the mining of felspar and mica.

The present chief use of beryllium is in alloys with copper. By adding from 1.75% to 2.25% of beryllium to copper and subjecting the alloy to special treatment, the tensile strength of the copper is increased sixfold and the high fatigue resistance of the alloy ensures durability. It is stated that 'by its use in some instrument parts, a life of 7 to 10 days has been increased by months'. The alloy is thus especially suitable for springs used in electrical devices, motion-picture cameras, switches, and recently in springs in aeroplane under-carriages, valves, electric motor brush-holders and collector rings. Beryllium-copper alloys, besides being hard and tough, have non-sparking qualities of great advantage in industrial plants where a spark might have disastrous effects. Beryllium-nickel alloys are also now in use. Metallic beryllium is employed as a deoxidizer and desulphurizer in steel-making and in the casting of copper. The pure metal has a limited application in the manufacture of 'windows' for X-ray tubes.

The nitrate of beryllium is employed for strengthening the oxide skeletons of incandescent mantles; beryllium oxide is utilized as a refractory for crucibles; and when beryl is substituted for felspar in the manufacture of porcelain, the product has very high electrical resistance and low

thermal expansion, making it an eminently suitable electrical porcelain, as for sparking-plugs. Salts of beryllium are occasionally used for pharmaceutical preparations and inorganic syntheses.

Beryllium has been described as the 'World's No. 1 metallurgical headache' owing to the metal's high fusion point, and high vapour pressure at a temperature not much above the fusion point.

### *Occurrence and Production*

The only important source of beryllium is the mineral, beryl,  $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$ , which contains about 5% of the metal. It is found chiefly in coarse-grained pegmatites, and occasionally in cavities in granites. At rare intervals, very large crystals of the mineral have been found: one in Maine in the U.S.A. measured 18 feet long, 4 feet in diameter and weighed 19 tons; and a few others, almost as large, have been discovered in Namaqualand, South Africa. These, however, are very exceptional and sporadic occurrences; usually deposits containing beryl are worked only when other minerals like felspar or mica are the chief products.

It is estimated that for the five years ended in 1930 the total world annual production of beryllium metal was under 200 tons, but reliable figures are not obtainable. The principal producing countries of beryl are Brazil, Argentina, the U.S.A., India, and South Africa; and the chief consuming countries in normal times were Germany and the U.S.A. In 1940 the U.S.A. imported 380 tons of beryl from Argentina, 340 tons from Brazil, and 6 tons from South Africa. During 1952 the chief producing countries were: Brazil, 2,440 long tons; Northern Rhodesia, 1,060; Southern Rhodesia, 529; U.S.A. 454; Madagascar, 389; Union of South Africa, 369; Mozambique, 230; French Morocco, 127 tons. The world production in 1952



was approximately 6,000 tons of beryl. The maximum amount of the metal that can be recovered from a high-grade beryl ore is usually not more than 3%, although the pure mineral contains 5% beryllium.

## BISMUTH

BISMUTH is associated in the public mind with medical preparations, and it is a fact that about three-quarters of world production of this metal is used in the form of the sub-carbonate, sub-nitrate, and sub-gallate in indigestion remedies, in cosmetics, ointments, and for the treatment of ulcers, etc.

'Bismuth meals', in which the metal is present as bismuth nitrate, are taken internally before photographs are taken of the digestive organs by X-rays, to which the nitrate is opaque. To a small extent the nitrate is also employed to produce a colourless iridescent glaze on porcelain, and bismuth salts are used in the manufacture of glass to give it high refractive power and thus a brilliant appearance. The smooth, unctuous feel of bismuth salts renders them especially suitable for cosmetics.

Bismuth metal has long been recovered as a by-product in the refining of certain lead and copper ores, but extensive use has not been made of it. Its principal employment is in combination with tin, lead, mercury, and cadmium for making fusible alloys, many of which will melt in hot water well below its boiling point, and some of which will melt even when held in the hand. Wood's metal, for example, contains approximately 68% bismuth, 18% tin, and 14% cadmium, and will melt at 60° C. Because these alloys fuse at such low temperatures they are particularly suitable as safety fuses for electrical apparatus, safety-plugs

in the blow-holes of boilers, and in automatic water-sprinkling devices which come into action as the result of the heat generated by accidental fires. They are used also for bending thin-walled tubes of other metals, the alloy forming the temporary filling of the tube being easily removed at the end of the operation by a steam jet; and for setting stamping dies that cannot be embedded in alloys of higher melting point. Bismuth wire has an important application in electrical apparatus and for measuring small intensities of heat and light. An amalgam composed of bismuth and mercury is used in dentistry; and because the alloys expand upon cooling, they give fine sharp castings of detailed work, as in the reproduction of woodcuts.

Bismuth is used in aluminium alloys (cerrobase alloys) from which the forged cylinder heads of air-cooled aviation engines are made, in order to increase machinability of the forgings. Considerable amounts of bismuth and bismuth alloys were used in the production of atomic bombs, and are now used in radar equipment, and in nuclear energy projects.

### *Occurrence and Production*

Two only of the bismuth minerals are of economic importance. They are native bismuth, or the metal itself as it occurs in nature; and the sulphide, bismuthinite,  $\text{Bi}_2\text{S}_3$ . These minerals are usually covered by a thin film of the yellowish oxide, bismuth ochre. It is unusual, however, to find bismuth minerals in workable amounts, and the bulk of the world's supply is obtained as a by-product in the smelting of other ores, such as those of copper, lead, gold, and silver.

Bismuth minerals are also frequently associated with the ores of tin, tungsten, and with base-metal sulphides as in

Bolivia, which twenty years ago was the chief source of supply of bismuth. The mines at Tasna near Potosi in that country were among the world's most important sources of the metal, the ores in places carrying from 20% to 30% of bismuth. During the last decade, however, the production of bismuth in Bolivia has, for various reasons, decreased considerably.

The leading producer until the last few years has been the Cerro de Pasco Copper Company, which operates copper and lead mines in Peru, the bismuth being recovered as a by-product in the smelters. That company during 1939 and 1940 averaged about 410 tons of the metal. Australia, an important producer of bismuth in 1914-18 from tungsten and molybdenum ore-pipes in Queensland and New South Wales, has now virtually ceased producing the metal.

Mexico, Peru, and Canada now rank respectively first, second and third among the producing countries, the whole output of Canada being recovered as a by-product during the smelting of lead and copper ores.

There is much fluctuation in the outputs of bismuth from different countries, and accurate figures are unobtainable. It is estimated that in 1939 world production was in the neighbourhood of 1,475 long tons of the metal, of which Peru produced about 30%, Canada 12.5%, Mexico 11%, Bolivia 1.1%; the remaining 45.4% was produced by various other countries.

In 1952 the chief producing countries were: Peru, 6,300 cwt. of bismuth metal; Mexico, 7,993 cwt. of bismuth ore; Yugoslavia, 1,943; Canada, 1,609; Korea, 1,108 cwt. of ore.

## BORATES

**BORAX** is most popularly known as a household commodity used for water-softening, in soaps, and to discourage

the depredations of ants and cockroaches, and boric acid brings to mind the ointment; but these are very minor applications of these two commercially most important compounds of boron. It is surprising, in fact, how wide is the range of industrial uses of borax and boric (or boracic) acid.

The chief use of borax is in the manufacture of porcelain enamels for coating iron and steel to make enamel ware such as kitchen utensils, baths, stoves, table-tops, saucepans, and so forth. Both borax and boric acid are also employed in making glazes for earthenware and chinaware, sanitary ware and glazed tiles. In the glass industry the use of borax is increasing, for it hastens the melting of the batch and increases the strength, brilliancy and durability of the glass; generally from 15 to 50 parts of borax are mixed with 1,000 parts of quartz sand. Also, special borosilicate glasses are now widely employed as cooking dishes of the 'Pyrex' type, and for flasks, beakers, lamp-chimneys, thermometers and optical glasses. The heat-resisting properties and low coefficient of expansion of borosilicate glass make it specially adaptable for uses involving high temperature and sudden fluctuations of temperature.

Borax is extensively utilized in the laundering of most fabrics, for dyeing textiles, in several processes connected with the conditioning of leather, and as a solvent of casein in the making of coated papers, plywood, plaster, and paint. A mixture of 70% borax and 30% boracic acid in water forms a useful fireproofing solution for fabrics, paper and wood. Borax, owing to its low melting point and its property of being able to dissolve metallic oxides, plays an important role as a flux in assaying, in the refining of precious metals, and in the melting of brass and various other alloys, and it is also widely utilized in the welding, brazing and soldering of iron, bronze, steel, copper, etc.

It is a constituent of certain starch preparations and of

soap, acts as a larvicide, as a disinfectant, and as a food preservative, especially for retarding the growth of mould on citrus fruits. Soils deficient in boron are treated with small quantities of borax to prevent, for example, the development of heart rot and the 'cracked stem' disease of celery.

In the field of medicine and pharmacy, both borax and boric acid have an antiseptic value, and are much used in lotions, ointments, cosmetics, medicated lint and gauze; and sodium perborate is employed in mouth-washes, tooth-powders, bleaching preparations and as a deodorant.

The element boron, which is a non-metal, has hitherto found few applications. Ferroboron is occasionally used as a deoxidizer and as one of the ingredients for making steel strong and tough. Boron and boron carbide are among the hardest artificial materials known, and the latter is likely in the near future to gain favour as an abrasive and to produce hard-bearing surfaces.

### *Occurrence and Production*

The list of boron minerals is a long one, but only about half a dozen are of commercial interest. Two of these, borax,  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ , and kernite,  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 4\text{H}_2\text{O}$  are of outstanding importance, although prior to 1926 the most important source of borax was colemanite,  $\text{Ca}_2\text{B}_6\text{O}_{11} \cdot 5\text{H}_2\text{O}$ . In Italy, however, considerable amounts of boric acid, known under the mineral name, sassolite,  $\text{H}_3\text{BO}_3$ , are obtained as the result of gaseous emanations from the volcanic fumaroles of Tuscany. Turkish supplies are derived from priceite, alternatively named pandermite, a calcium borate mineral occurring with gypsum in old lake-beds where boracic acid solutions or vapours of volcanic origin were present.

Borates, chiefly in the form of borax, are typically found in the neighbourhood of hot springs and in lakes of volcanic

regions. It was from such dried-up lakes in Tibet that borax was first obtained more than 350 years ago and from which small quantities have been exported ever since. The mineral is deposited as a thick encrustation by the evaporation of the water in these and similar salt lakes, and as an efflorescence on the surface of desolate, arid plains such as those between the bleak ranges of volcanic rocks in the deserts of California, Nevada, Argentina, Bolivia and Chile. For many years Chile was second only to the U.S.A. as a producer of crude borates, but Chilean output virtually ceased in 1929. Deposits of colemanite in the Death Valley of California supplied the bulk of the world's borax for the forty years between 1887 and 1927, when the discovery in 1926 of a new mineral, kernite, a sodium borate first found in Kern County, California, heralded the rapid decline in the production of colemanite. Kernite associated with borax forms, near Kramer in the Mohave Desert of California, a deposit some four miles long, a mile wide and some 100 feet thick, lying at a depth below the surface of about 400 feet. It is now the world's chief source of borax. Kernite dissolves easily in water and, after evaporation to form a saturated solution, normal borax crystallizes out. It is the simplicity and cheapness of this process that caused the closing down of the colemanite mines. Practically the whole of the U.S.A. production of borax is now obtained from beds of kernite and from the Searles Lake playa of California.

The origin of borax is intimately connected with present or past volcanic activity, the compound of boron being emitted in vapours and exhalations escaping from fumaroles and solfataras. The vapours become dissolved in the waters, and the boron compounds are deposited by natural evaporation as surface efflorescences or as lake deposits, which later may become buried beneath newer sediments. Volcanic activity, past or present, and arid climate are prerequisites

for the formation of all commercial deposits of borates.

The borax industry for a long period of years has virtually been controlled by the U.S.A., which between 1920 and 1928 produced 65% of the world supply; this increased to 93% for the period 1929-36; and for the peak year of 1937, when world output reached 341,500 long tons, the U.S.A. supplied almost 94% of the total, the remainder being from Argentina 3%, Italy nearly 2%, and Turkey about 1½%. In 1952 the U.S.A. produced 521,275 long tons of crude borates; Turkey, 13,513; Italy, 4,283 tons. The geographical distribution of the chief borax fields is shown in Fig. 28.

## CADMIUM

CADMIUM is comparatively a new-comer among metals, but has already established itself firmly in a very important field of service to man. When it was discovered that the metal could be recovered as a by-product in the electrolytic zinc process, no use was known for it, and early attempts at its substitution for tin, as in solder, proved unsuccessful. Later, its valuable properties in producing rust-proof coatings on steel became known, and then followed its utilization in high-pressure bearing alloys, which heralded the rapid increase in its consumption, which in 1938 reached 4,500 long tons.

Cadmium-bearing alloys have proved stronger, to withstand higher temperatures, and to have a lower coefficient of expansion than the popular babbitt-metal bearings. Cadmium-nickel alloy, with about 98% cadmium, and 'silver'-alloy, with 97.5% cadmium, 2.25% silver and a quarter per cent copper, are now widely employed in automobiles.

In recent years cadmium has been extensively used in plating other metals, especially iron, on which it forms a resistant rust-proof coating that is less liable to peel off than coatings of nickel. The nuts, bolts, locks and other fittings in automobiles often have a coating of cadmium.

A comparatively long-established application of the metal is in the manufacture of fusible alloys with bismuth, lead and tin, as in Lipowitz's and Wood's metals for electric fuses, fuse-plugs for automatic fire-extinguishers, and various other safety devices. It is being utilized also as a substitute for bismuth in cliché metal for stereotype plates, to increase the effective life of the alloy. A little cadmium added to silver has a hardening effect, and is utilized in sterling silverware; and it has a somewhat similar effect on lead used for the casings of electric cables. Nickel-cadmium alkaline electric storage batteries, which stand a rapid discharge rate without deterioration, are used in railroad units, miners' lamps, and for aircraft service.

Cadmium salts find many uses in chemicals, photography, fireworks, fluorescent paint, rubber, dyeing, and in the manufacture of coloured glass and porcelain. The sulphide is a brilliant and durable yellow pigment known as 'cadmium yellow', and with selenium gives the vivid red pigment, 'cadmium red'. Cadmium pigments such as cadmium lithopone ('cadmopone') are available in a full range of yellow to orange to red colours which are stable for temperatures up to  $500^{\circ}\text{C}$ . Cadmium sulphate is employed in making standard electrical cells.

Rods of cadmium metal are now used as neutron-absorbing material in atomic piles.

### *Occurrence and Production*

All the cadmium of commerce is obtained as a by-product in the treatment of zinc ores, in which it is present as a sul-



phide in intimate association with zinc blende, or sphalerite. The only cadmium mineral of importance is the yellow sulphide, greenockite,  $\text{CdS}$ , which never occurs as a separate mineral in sufficient quantities to be workable. Even in the zinc ores which are notably rich in the metal the percentage of cadmium is rarely half of one per cent, and in the world's most productive zinc and cadmium field, namely, the Tri-State region of Oklahoma, Kansas and Missouri in the U.S.A., the ores average only about 0.3% cadmium. In Canada, cadmium is a by-product from the electrolytic extraction of zinc derived from the ores of the famous Sullivan Mine in British Columbia and Flin Flon Mine in Manitoba. In 1938 Canada produced 200 tons of cadmium. The Silesian lead-zinc deposits of Germany and Poland contain cadmium, as also do many Mexican lead-zinc ores. About 200 tons of cadmium are produced annually in Australia, most of which is recovered from zinc concentrates treated by the Electrolytic Zinc Co. of Australasia at Risdon, Tasmania.

The average annual world production for the quinquennial period 1934-8 was 4,045 long tons, of which the U.S.A. yielded 46%, Mexico 14%, Canada 7%, Germany 7%, Australia 5%, Poland 4%, and Belgium, from imported zinc ores, 5%. The rapid increase in the applications of cadmium during the last decade is shown by the U.S.A. production figure, which in 1931 was only 620 tons; in 1936 it increased to 1,900 tons; and in 1940 reached 3,000 tons.

On account of its high cost (£1,500 to over £2,000 a ton) the production figures of cadmium are usually given in lb. avoirdupois. In 1952, the U.S.A. produced 8,387,824 lb.; Mexico, 1,618,390; Belgium, 1,213,000; South-West Africa, 1,112,000; Canada, 1,004,623 lb. France, Italy, Norway, Poland, Belgian Congo, and Japan also produced cadmium.

## CHINA-CLAY (KAOLIN)

It will come as a surprise to some readers to learn that of all the *raw* materials exported from the United Kingdom in normal times, china-clay ranks second in tonnage, coal being the chief. Most of this clay is obtained in the neighbourhood of St Austell in Cornwall, and some from Dartmoor and Bodmin Moor, but nowhere in this country outside Cornwall and Devon have workable deposits of china-clay been located, and there are strong geological reasons for stating that none can be expected to occur here except in these two counties.

The daily newspaper contains about a tenth of its weight of china-clay; and in periodicals, all kinds of books and writing-paper, wrapping-paper and in almost every form of paper it is the chief filler in the pulp to produce the body of the paper and its smooth surface. The clay is an essential constituent in the bodies and glazes of cups, saucers, plates, and other kinds of ceramic ware, including porcelain electrical insulators; it is used very extensively in the rubber industry as a filler; it finds wide and increasing applications in the paint industry; and many thousands of tons of it are used annually in this country and others as a stiffener for cotton and other textile fabrics. These are some of its chief industrial uses. The normal consumption in this country alone for paper, pottery, rubber, paint, and textiles is for each industry more than 15,000 tons a year; and for some, such as the paper industry, which is the main consumer, about five times that tonnage is consumed annually. It has several other important applications, such as a filler and surface coating for linoleum and oilcloth; as a mild abrasive in polishes, cleansing soaps and tooth-powders; as a

filler in certain wall-plasters and as a constituent in the manufacture of white Portland and other cements. Specially prepared china-clay of extremely fine grain-size is valuable for medicinal purposes, partly as an absorbent of toxins in the alimentary canal and as the basis of various disinfectant powders; for the manufacture of high-quality rubber such as is used for medicinal gloves, fuse coverings and so forth; for cosmetics and for certain plastics. White inert substances like barytes and talc can for many purposes be replaced by china-clay; and the mineral may in future be used on a commercial scale as a source of alumina for the manufacture of aluminium.

### *Occurrence and Production*

China-clay, so called because samples of it were originally obtained in the eighteenth century from China, is also known as kaolin, a corruption of the Chinese word 'Kauling', the 'high ridge' or Kuling range to the east of King-te-chen, the large town in Kiangsi which for centuries has been the chief centre in China for the manufacture of pottery, and which the author visited in the early part of 1914. The china-clay does not, however, occur in that part of Kiangsi on the high ridge, but at Nankan Fu, where it is washed, dried in the form of briquets, and transported in boats to King-te-chen.

All the china-clay deposits of the world are the product of the decomposition of feldspars in granite or in granitic rocks. This decomposition or kaolinization may be effected in three or four ways, but the two chief are: (a) by ascending gases and vapours, chiefly of carbon dioxide and superheated water vapour, which emanated from a deep-seated acid igneous magma, and (b) by downward percolating surface waters containing carbon dioxide, organic acids and other substances which, like the ascending vapours, leached

out the potash in the felspar and left a residue of kaolin, a hydrated aluminium silicate,  $2\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ , mixed with quartz, mica and other minerals from the granite.

It is fortunate that the china-clay deposits of Cornwall and Devon were formed *in situ* by ascending gases and vapours, for whereas those formed by descending waters are in general of shallow depth, those in the south-west of England persist to a depth that has nowhere yet been bottomed, and in the deepest pits, some well over 300 feet below the surface, the china-clay is of the highest quality. It is true that some Cornish pits have been abandoned because the kaolinization became more restricted in depth, but they were not the deepest pits, nor those worked in such a manner that the sides of the pit were kept in a state to enable the clay to be followed to greater depth. The important Czechoslovakia china-clays and those of France and China occur in well-kaolinized granitic rocks.

Some china-clay deposits are not, however, *in situ*, or in the place where they were originally formed. The clay in these has been transported by water from the kaolinized granite and redeposited some distance away as clay beds frequently referred to as 'residual kaolins' or 'sedimentary kaolins'. There are valuable deposits of this type in parts of the U.S.A., chiefly in Georgia and North Carolina. This type of china-clay is very suitable for paper-making, but is inferior for the manufacture of high-grade creamware to the 'pottery clays' produced in Cornwall and Devon. China-clay occurs extensively in Malaya and parts of Thailand, and doubtless will be worked some time in the future. Extensive kaolin deposits have been discovered in recent years in the Pugu Hills, near Dar-es-Salaam in Tanganyika, but hitherto have not been worked.

In 1937 (later reliable figures are not obtainable) the world production of china-clay, excluding the U.S.S.R. and

China, for which figures are not available, was 3 million tons, of which Cornwall and Devon yielded 831,000 long tons, or 27% of the incomplete total, the U.S.A. 21%, Czechoslovakia 14.5%, Japan 13%, Germany 12%, Italy 4%, France 4%, Denmark 1.3%, other countries 3%.

During the twenty years ended in 1938 Cornwall and Devon together produced about three-quarters of a million tons annually, and until a few years ago shipped well over a quarter million tons a year to the U.S.A., before that country had developed its domestic resources of the mineral. In normal times large shipments, mainly from Fowey and Par on the south coast of Cornwall, are made annually to the U.S.A. and India, Japan, and European countries, where the unsurpassed quality of the clay and the care exercised in preparing it for market have established for it the highest reputation.

In 1952 the chief producing countries were: U.S.A., 1,612,154 long tons; Great Britain, 790,276; Germany (Federal), 278,564; Austria, 198,652; France, 105,000 tons. Spain, India, and the Union of South Africa were also large producers.

## CHROMIUM

CHROMIUM-PLATING on motor-car and on domestic hardware fittings is probably the most familiar use of the metal, but its chief application in industry is in the manufacture of various alloys, particularly of chromium steel, and for refractory purposes. Approximately 45% of the world's supply is used for alloys, about 40% for refractories, and 15% for chemical purposes.

The addition of small or moderate amounts of chromium, with or without other alloying agents, imparts to carbon

steel increased hardness, tenacity, ductility, resistance to wear and corrosion, and high electrical resistance. The chromium is added in the form of ferro-chrome, a chromium-iron alloy usually prepared by reducing the chrome ore, chromite, in an electric furnace in the presence of carbon.

Steels with a chromium content of less than 3.5% are used extensively in the automobile industry and in high-strength steels for tanks, omnibus bodies, railway carriages and bridges. Chromium alloys with more than 12% of the metal include stainless or rustless steels for cutlery and other domestic utensils and for chemical plants. Stainless chromium-nickel steel, containing usually 18% chromium and 8% nickel, has a wide application in the chemical industry in dyeing, and in dairy, electrical and marine engineering. The great strength and light weight of such alloys render them especially suitable for aircraft, warship superstructures, armour-plate and rifles. The only commercial use of pure chromium metal is in the form of electroplate.

For refractory purposes the crude ore is embodied in bricks, cements and plasters in the construction of furnaces. Usually the chromite is employed as a chemically neutral insulating layer between a basic hearth of magnesite brick and an acid roof of firebrick or silica brick. A new type of refractory bricks, known as chrome-magnesite bricks, is now used in many steel furnaces.

In the chemical industry, chromates and bichromates are used in tanning and dyeing, as paint pigments (yellows, reds and greens), as oxidizing agents, and for the production of other chromium compounds.

Chromium salts are used in photography, for bleaching oils, and in the manufacture of safety matches; and the finely powdered oxide is a good polishing medium.

### *Occurrence and Production*

The only ore mineral of chromium is chromite, theoretically  $\text{FeO} \cdot \text{Cr}_2\text{O}_3$  with 68%  $\text{Cr}_2\text{O}_3$  and 32%  $\text{FeO}$ . Almost invariably, however, impurities are present, and the commercial ore seldom contains more than 50%  $\text{Cr}_2\text{O}_3$ . Chromite varies in colour from dark brown to black, and occurs either in massive form as lenses and tabular bodies, or disseminated as granules and streaks in ultra-basic rocks like serpentine and others, and occasionally in rocks adjacent to ultra-basic rocks. Nearly all chromite deposits of economic importance are magmatic segregations, the chromite

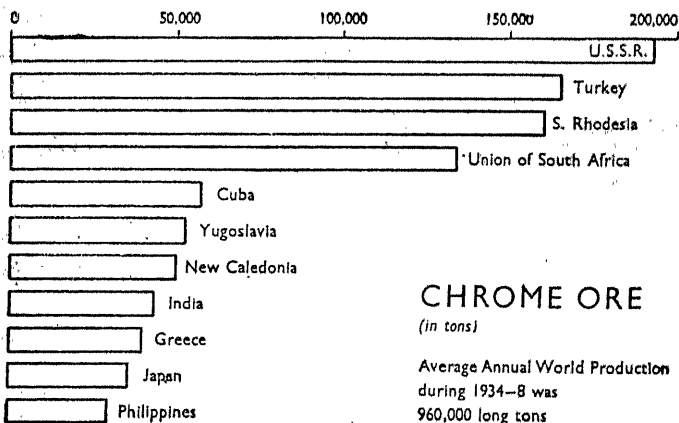


Fig. 6.

crystallizing during the early and late stages of consolidation, and some few deposits are of hydrothermal origin. Owing to its resistance to weathering agents, disseminated chromite is often concentrated at the surface to form valuable deposits after the removal by erosion of the more easily weathered enveloping rock.

During the quinquennial period 1934-8 the average

annual production of chromite was nearly one million tons, the leading producing countries being the U.S.S.R., Turkey, Southern Rhodesia, and the Union of South Africa. The Philippines between 1934 and 1938 produced only 3% of the world's supply, but in 1940 this had increased to 16%. It is estimated that there are in these countries sufficient reserves of ore for many years' supply, the reserves of the Union of South Africa probably being the largest in the world. The increasing demand for the mineral is shown by the following figures: the world output in 1920 was 213,000 long tons; in 1929 it was 580,000 tons; and in 1937 it was over 1½ million tons.

During the five-year period ended in 1952, the average annual production of chrome ore in the chief producing countries was: U.S.S.R., 520,000 long tons; Turkey, 498,730; Union of South Africa, 480,000; Philippine Republic, 321,280; Southern Rhodesia, 273,350. For this quinquennial period, the average annual world production was 2,441,600 long tons.

It is interesting to note that, with the single exception of the Soviet Union, all the major steel-producing countries are markedly deficient in domestic supplies of chromite and have to rely upon imports for their requirements. The U.S.A., the principal steel-manufacturing country, and thus the largest user of chromium, normally produces less than 1% of what it consumes. The geographical distribution of the chief chromite fields is shown in Fig. 30.

## COBALT

THE beautiful blue glass found 'in the tombs of the ancient Egyptians and in the ruins of Troy', and the deep blue glass in the windows of cathedrals and churches and in poison



bottles, derives its colour from cobalt. Indeed, until comparatively recent years the principal use of cobalt and its compounds was in the manufacture of pigments, especially blues, occasionally greens, and rarely pinks, for colouring glass, enamel, pottery glaze, and paints. Cobalt oxides are still used in ceramics, but cheaper pigments have largely been substituted for them in paints other than artists' colours.

It is in the metallurgical field that cobalt now finds greatest application, especially in the manufacture of rustless alloys of the stellite type and for cobalt steels. Probably the most important use of the metal is in stellite alloys for high-speed cutting tools, a typical alloy of which contains 60% cobalt, 25% chromium and 15% tungsten or molybdenum. Cobalt alloys are now used under high-temperature conditions, including jet engine parts. Cobalt steels possess many of the valuable properties of nickel and tungsten steels.

Certain ferrous and non-ferrous cobalt alloys are utilized for making strong and remarkably permanent magnets capable of lifting heavy loads, 'sixty times the weight of the magnet'. Corrosion-resisting steels suitable for safety-razor blades and surgical instruments frequently contain cobalt, and the best binder for tungsten carbides and similar superhard cutting materials is stated to be cobalt. As a catalyst, cobalt is now rapidly gaining favour, the most common use in this direction being as a drier for promoting the oxidation of vegetable oils in paints. The hard and brilliant surface produced by cobalt in electro-plating has been known for many years.

Cobalt fluoride is used as a fluorinating agent in the synthesis of fluorocarbon compounds utilized in the separation of uranium isotopes. Cobalt compounds have important applications in the field of animal husbandry.

### Occurrence and Production

Practically all the world's cobalt is recovered as a by-product from complex ores which are mined mainly for other metals, such as the copper and silver which they contain. The cobalt is present usually in the form of sulphides, arsenides and sulpharsenides. The most important cobalt minerals are linnaeite,  $\text{Co}_3\text{S}_4$ , smaltite,  $\text{CoAs}_2$ , and cobaltite,  $\text{CoAsS}$ , which occur as primary minerals. In the upper and oxidized parts of the ore-body the beautiful peach-red cobalt 'bloom', erythrite, is not uncommon.

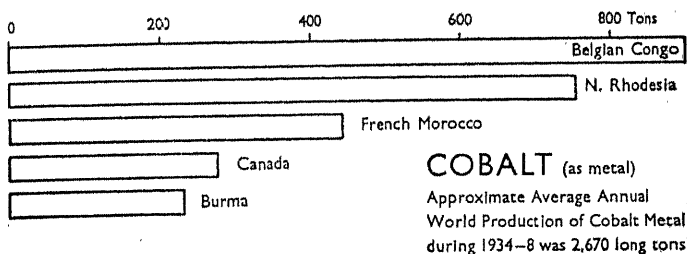


Fig. 7.

Twenty years ago the chief source of the metal was in the neighbourhood of Cobalt, Ontario, where smaltite and cobaltite occur in veins worked mainly, however, for their silver content. Activities in that district have decreased greatly in recent years, and at present the chief sources of cobalt are the copper deposits of Northern Rhodesia and Katanga in Belgian Congo. In these two countries the chief primary cobalt mineral is linnaeite, though the oxide of cobalt is locally dominant in the weathered parts of some of the deposits, especially of those in Katanga, which carry from 2% to 4% cobalt, as against an average of about 0.5% in the Rhodesian ores. The cobalt is recovered

during the metallurgical treatment of the copper ores in the form of copper-cobalt-iron alloys containing some 40% cobalt. The third largest producer of cobalt is French Morocco, where smaltite and erythrite occur in gold ores. Before the Japanese occupation, Burma was producing about 250 tons annually from nickel speiss.

In 1910 the total amount of cobalt used in industry was 250 tons; in 1920 it was 750 tons; in 1930 it had increased to 1,250 tons and in 1939 it had reached 4,000 tons. The geographical distribution of the chief cobalt-producing fields is shown in Fig. 30.

During the five-year period ended in 1952, the average annual production, in terms of the metal, of the chief producing countries was: Belgian Congo, 5,196 long tons; Northern Rhodesia, 551; French Morocco, 525; Canada, 447; U.S.A., 383 tons. For this quinquennial period, the average annual world production was 7,114 long tons.

## COPPER

COPPER was most probably the first metal used by man, and no other metal has rendered such dependable service for so many uses and for so long a time. It happens that in some countries it is found naturally on the surface as a metal, is soft, and can readily be shaped into ornaments and vessels. Copper can also be reduced easily from its ore minerals, and as these are usually mixed with other minerals, the copper produced is harder than the pure metal, for almost any other metal alloyed with copper hardens it, and some metals lower its melting point. Tin is particularly useful for this purpose, and because copper and tin may occur together, as for example in parts of Cornwall, the copper-tin alloy called bronze was in early

days probably discovered accidentally. All the objects labelled bronze in archaeological collections are not, however, copper-tin alloys, but range from almost pure copper to copper alloys containing lead, zinc, nickel, etc., as well as tin.

In ancient times, before man had learnt how to control the carbon content of iron, bronze was the best material for making knives, axes and swords. That period is termed the 'Bronze Age', and followed the 'Stone Age', although many archaeologists believe that a 'Copper Age' intervened between the two. Copper was used more than 15,000 years ago for colouring beads and glazes, and the Egyptians, who may have been the first to extract the metal from its ores, employed it for utensils, weapons, and ornaments, and this knowledge had spread throughout Europe by about 4000 B.C.

On account of its high electrical conductivity, copper finds its greatest utilization in the electrical industry. About a quarter of the world's production is used in generators, motors, switchboards and other electrical apparatus; over 8% for transmission lines for power and lighting; and 5% for telephones and telegraphs. Other rod and wire uses consume 12%; bearings, bushes and fittings 4%; radio sets over 3%, and the remaining 43% or so serves for the various copper alloys and numerous other uses.

Ancient bronzes contain about 88% copper and 12% tin, but present-day bronzes are commonly composed of 88% copper, 10% tin and 2% zinc. Statuary bronze, however, has 80% copper and 20% tin. Gun metal, with 90% copper and 10% tin, is resistant to corrosion.

More important industrially than the bronzes are the brasses, alloys of the copper-zinc group. These are cheaper than either bronze or copper, and are used mainly in the

form of sheets, strips, wires, rods, pipes, tubes, and castings. Brass is easily machined, spun, and stamped, and well resists corrosion. Large quantities of brass are used during war-time for cartridge cases, shell cases, etc. Cartridge brass, with 70% copper and 30% zinc, is the toughest and strongest of all brasses.

Other important copper-bearing alloys include Monel metal, a copper-nickel alloy; nickel-silvers, used as a basis for silver-plated table and other ware; and duralumin, a copper-aluminium alloy with 95% aluminium, 4% copper and with the remaining 1% of silicon and magnesium. Duralumin is extensively used for aeroplane construction and for other purposes where lightness and strength of the material are important. The copper coins in this country contain about 95% copper and 5% zinc and tin.

The salts of copper have many industrial applications. The chloride is a powerful disinfectant; the sulphate ('blue vitriol') is employed in calico-printing, dyeing, for preserving timber and as a fungicide on grape-vines and other plants; and certain copper salts are utilized for colouring glass.

In the U.S.A., for every ton of 'new copper' - that is, copper which has not been used previously in industry - about three-quarters of a ton of the metal is recovered from copper scrap.

### *Occurrence and Production*

Copper occurs in nature in the form of metal and as sulphide, carbonate, or oxide, and in combination with other elements. Of all metals it is the one that forms the largest group of minerals, some 360 of which have been given specific names. Among the chief are native copper, that is, the naturally occurring metal; cuprite,  $\text{Cu}_2\text{O}$ ; chalcocite,  $\text{Cu}_2\text{S}$ ; covellite,  $\text{CuS}$ ; bornite,  $\text{Cu}_5\text{FeS}_4$ ; the car-

bonates malachite and azurite; enargite,  $\text{Cu}_3\text{AsS}_4$ ; the silicate, chrysocolla; and the most common of all, chalcopyrite,  $\text{CuFeS}_2$ .

Copper minerals, particularly the sulphides, are unstable in the presence of natural weathering agencies, and hence copper deposits are especially prone to oxidation and enrichment. The chief primary, or original, copper mineral is chalcopyrite, which, within the near-surface zone of

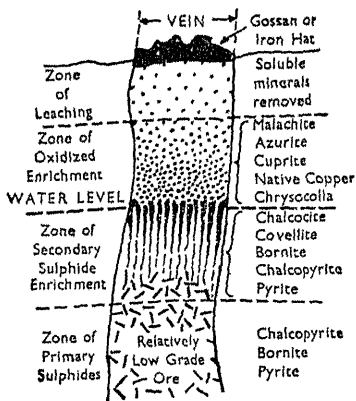


Fig. 8.

weathering, frequently becomes decomposed by oxidation to form the spectacular green and blue copper carbonates, malachite and azurite. Much or even all of the copper content may, however, be carried downwards as a soluble sulphate, leaving on the surface a zone from which the copper has been leached and where the iron, now changed to limonite, remains to form a reddish-brown gossan, or capping, referred to by miners as the 'iron hat'.

The copper thus carried downwards in solution may be redeposited some distance below the surface in the form of the sulphides, chalcocite and bornite, which are much

richer in copper than the original chalcopyrite, for whereas chalcopyrite contains only 34.5% copper, chalcocite has 79.8% and bornite 63.3% copper. This process is referred to as 'secondary enrichment'. Other copper minerals may arise by oxidation and by reduction, as shown in Fig. 8. In arid regions where wind-blown salt (sodium chloride) from

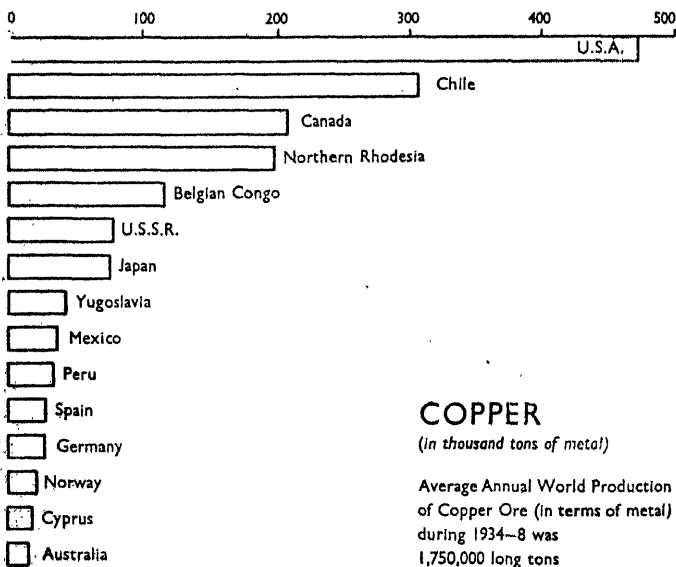


Fig. 9.

the sea is present, the copper may form the mineral atacamite,  $\text{Cu}_2\text{Cl}(\text{OH})_2$ ; and the basic sulphate, brochantite,  $\text{CuSO}_4 \cdot 3\text{Cu}(\text{OH})_2$ , may also be deposited. These two minerals are among the chief sources of copper at Chuquicamata, Chile, the largest copper-producing mine in the world.

The zone of sulphide enrichment, sometimes referred to as the 'chalcocite zone', varies in thickness from a few

feet to 1,000 feet and more, according to the climate, depth to groundwater level, composition and texture of the rocks and of the ore. Normally, the rich chalcocite zone is succeeded in depth by the primary or lean zone, in which the copper minerals, usually chalcopyrite, are in their original state.

Where very large tonnages of ore are easily accessible, copper deposits averaging even less than 1% copper can be mined profitably on large-scale methods dealing with thousands of tons of ore per day.

Copper ores occur in igneous, sedimentary and in metamorphic rocks in a great variety of ways. There is strong evidence, however, that in most cases the copper minerals were deposited by hot ascending solutions emanating from an igneous source. Except in a few instances, as at Butte in Montana (one of the richest copper-producing districts in the world), copper-bearing veins are seldom of importance, unless there has been replacement of the wall rocks and subsequent enrichment of the ore. In disseminated deposits the copper minerals are scattered through the rock, which is mined and milled on a large scale. In the Lake Superior district of the U.S.A. metallic copper occurs in steam holes and small fissures in lava flows, as the cementing material between pebbles of a conglomerate, and as replacements in beds of volcanic ash.

The so-called 'porphyry coppers', many of which are not in porphyry at all, are one of the chief sources of the metal in the U.S.A. They are low-grade disseminated copper sulphide ores where the lean primary ores have been enriched by secondary processes, especially to chalcocite. Examples of these are the famous deposits at Bingham in Utah, Ely in Nevada, Cananea in Mexico, Chuquicamata, Braden and Potrerillos in Chile. The Utah Copper Mine (Kennecott) in Bingham is by far the largest copper producer in the U.S.A.



During the last twenty years enormously large deposits of disseminated sulphide copper ores have been discovered in pre-Cambrian sedimentary rocks at Katanga in Belgian Congo and in the adjoining part of Northern Rhodesia, which are now among the chief copper-fields of the world. The ore-bodies in Northern Rhodesia and some of those in Belgian Congo are bedded deposits, in form not unlike coal-seams, and their extent and mineral content could thus be ascertained with a high degree of certainty in a comparatively short period by diamond drilling. According to tentative estimates published in 1936, the Northern Rhodesian reserves were 550 million tons of ore, averaging 4.11% copper, and those of the Belgian Congo from 40 to 80 million tons, averaging 7% copper.

The U.S.A. has been the world's chief copper-producing country for the past fifty years; indeed, between 1895 and 1927 it yielded more copper than the combined production of the rest of the world. Increased production in Chile, Northern Rhodesia, Belgian Congo, and Canada has taken from the U.S.A. its former control of the world's copper, although it still remains the largest producer of the metal.

During the five years ended in 1952, the average annual production, in terms of the metal, of the chief producing countries was: U.S.A., 776,733 long tons; Chile, 386,452; Northern Rhodesia, 281,856; U.S.S.R., 258,000; Canada, 232,254; Belgian Congo, 171,352; Mexico, 59,800; Yugoslavia, 38,675; Japan, 38,257. For this quinquennial period, the average annual world production was 2,472,000 long tons.

The geographical distribution of the chief copper fields is shown in Fig. 27.

## CRYOLITE

THIS interesting mineral was at one time the only source of aluminium, and, although it has long been superseded by bauxite, now the chief source, it still remains of outstanding importance in the aluminium industry (see page 27), for it serves, better than any other mineral, as the solvent for alumina in the electrolytic process of extracting aluminium from the bauxite ore; and this is its chief use. It is now, in some countries, being replaced by artificial cryolite, owing to high cost and difficulty of supply. The few other uses of cryolite are in the manufacture of enamel for iron and steel ware, of white and opalescent glass and glazes, as electrical insulating material, insecticides, and as a flux for cleansing metal surfaces. It is also an important source of fluorine.

The word 'cryolite' is derived from the Greek equivalent of 'frost' and 'stone'. and was so named from its resemblance to ice. The mineral melts easily, even in a candle flame, hence its value as a flux for metallurgical purposes.

*Occurrence and Production*

The only commercial source of natural cryolite is at Ivigtut, on the western coast of Greenland, where the mineral occurs in a pegmatite dyke traversing granite. Associated with the cryolite are siderite, galena, chalcopryrite, zinc blende, and fluorite; and the cryolite deposit at the surface is approximately 500 feet long and 160 feet wide, and has been worked to a depth of 200 feet.

During 1937-9 inclusive, Greenland shipments averaged 50,000 long tons annually, of which about two-thirds were

exported to Denmark and one-third to the U.S.A. For the decade ended in 1937 the shipments averaged 28,500 long tons, the increase being due to the great expansion of the aluminium industry. Most of the cryolite used in recent years as a solvent of alumina for extracting aluminium from bauxite is made artificially.

## DIATOMITE

DIATOMITE has various names, such as diatomaceous earth, diatomaceous silica, kieselguhr, tripolite, and, erroneously, infusorial earth. It is a hydrous or opalescent form of silica, and the deposits are accumulations of myriads of microscopically small siliceous shells of diatoms, a group of flowerless aquatic plants of marine or fresh-water origin called algae. A cubic inch of diatomite contains from 40 to 70 million diatoms. When dry, diatomite is a whitish substance not unlike chalk in appearance, but much lighter in weight, more porous, and capable of absorbing about three times its weight of water. These properties, with its chemical inertness and relatively low thermal conductivity, account mainly for its importance as a filling medium and as an insulator against heat, cold and sound.

Formerly it was used mainly in the manufacture of dynamite, but not now. One of its most extensive applications is in filtration, especially in sugar-refining; also for filtering malt products and extracts, fruit juices and beverages, mineral oils including petroleum products, sewage, slimes, crank-case and waste oils, perfumes and vitamin extracts. In the form of powder or of bricks, diatomite is widely utilized for insulating purposes in furnaces, ovens, boilers, pipe-covering preparations, refrigerators, buildings, and for sound-proof rooms. It is also used as a light-weight

filler for paints, varnishes, battery boxes, rubber, gramophone records and synthetic plastics; as an absorbent in the purification of acetylene gas, on catalyst supports, and as a convenient carrier of nitro-glycerine explosives. Metal polishes contain diatomite as a mild abrasive; it forms part of the admixture in certain kinds of concrete; and it has a host of other uses.

### *Occurrence and Production*

Diatomite is of organic origin, and consists of the fossil remains of diatoms. Living diatoms secrete an external shell of clear silica, and when the algae die, the shells sink to the bottom, where the organic parts decompose and the silica skeletons accumulate in great profusion to form beds of varying thickness. In the course of time these beds become more or less compacted, and may attain a thickness of many hundreds of feet. Diatoms live to-day in hot springs as well as in the coldest waters, salt and fresh, but are most abundant in the Arctic and Antarctic regions. Many authorities believe that where thick diatomaceous deposits were formed, the waters contained unusually high concentrations of dissolved silica and perhaps of suspended silicates. The silica could have been derived, it has been suggested, from the products of contemporary vulcanism in the form of lava-flows and pumice. Possibly, a low degree of ocean salinity may account, in part at least, for some of the thick and extensive deposits of Tertiary age, since it is known that present-day diatoms flourish under such conditions.

All the chief economic deposits were formed during Tertiary, especially Miocene, times, and are now high above present water level as dry, compact beds, whereas those now accumulating are usually on lake-bottoms and in swamps and marshes.

The largest known are the marine deposits of Miocene age near the coast of California, which locally exceed 1,000 feet in thickness. In 1938 world production of diatomite exceeded a quarter million tons, of which the U.S.A. contributed over 100,000 tons and Denmark about 90,000 tons. Other important sources are Japan, Algeria, and U.S.S.R.

In 1952, the chief producing countries of diatomaceous earth were: U.S.A., 260,000 long tons; France, 60,000; Germany (Federal), 47,000; Algeria, 19,700; Great Britain, 17,000 tons. The average annual production of the world during the five years ended in 1952 was approximately 500,000 tons.

Crude diatomite is sold to the trade in the form of sawed blocks, crushed aggregates, or powder. Usually the diatomite is dried and calcined before marketing.

## FELSPARS

DURING the past decade the principal use of feldspar has been in the manufacture of glass, and more than half of the total world production of the mineral is now consumed for that purpose. Thirty years ago it had not been appreciated that the alumina content of feldspar rendered it valuable for glass-making, and little of it was used, but scores of thousands of tons are now employed in making bottles, plate and window glass, opalescent glass, and glassware for illuminating purposes. Nepheline is now being used in Canada to replace feldspar for the manufacture of special kinds of glass.

More than a third of the total production is still consumed in the ceramic industry, which formerly was the chief consumer. The feldspar forms part of the body of the ware, and is also an important constituent of the glazes on pot-

tery, chinaware, tiles and so forth. This is because it fuses at a lower temperature than clay, and on cooling forms a hard, transparent and durable glaze. High-grade potash felspar is required for electrical porcelain insulators and for artificial teeth. An important use is that for making enamels for sanitary ware, household utensils, and for coating sheet-iron.

Among minor uses of the mineral are as an ingredient in scouring soaps and mild abrasives; for roofing and cement surfacing, as a ceramic binder for abrasive products, and in poultry grit. Felspar was used during the closing stages of World War II for making a plastic body armour and glass-cloth combat jackets for ground troops.

### *Occurrence and Production*

The felspars are the most abundant of all rock-forming minerals, being the chief constituents of most of the igneous rocks. They form a group of aluminium silicates of potassium, sodium, and calcium, but the most important commercial varieties are orthoclase and microcline, both potassium aluminium silicates; and albite, a sodium aluminium silicate.

Although so common in nature, workable deposits are in general found only in coarse-grained pegmatite veins where the felspar crystals are sufficiently large for easy separation from the quartz when the rock has been crushed. In some pegmatite veins, crystals of felspar up to 4-5 feet are not uncommon, and parts of the pegmatite veins may be composed almost entirely of that mineral. The felspar in pegmatite veins was probably formed direct from the igneous magma during its slow consolidation.

The most productive felspar fields in the world are in North Carolina, South Dakota, and New England in the U.S.A.; and important deposits occur also in parts of the

pre-Cambrian areas of Canada, chiefly in Ontario, Quebec, and Manitoba. Sweden and Norway have long provided the bulk of the felspar used in European potteries, including those in this country. Near St. Austell in Cornwall, and in parts of Scotland, small quantities of felspar are extracted; and china-stone, a hard rock powdered for use in pottery-making, and containing some felspar, is also mined extensively near St Austell.

World production of felspar in 1937 (except for U.S.S.R. and China, the figures for which are not available) was nearly 570,000 tons, of which the U.S.A. contributed 47%, Manchuria 13%, United Kingdom (including china-stone) 11%, Sweden 8%, Czechoslovakia 5%, Norway 4%, Canada 3% and Italy 2%.

In 1952, the chief producing countries were: U.S.A., 420,830 long tons; Germany (Federal), 117,407; France, 59,000; Great Britain (China-stone), 48,729; Sweden, 40,000; Italy, 25,000; Norway, 21,700 tons.

The average annual world production for the five years ended in 1952 (excluding U.S.S.R. etc.) was 780,000 tons.

## FLUORSPAR

THE once-fashionable dark-blue or purple vases and ornamental table-tops of Victorian days now often seen in museums and antique shops are made of fluorspar or fluorite, or, as it is locally termed, 'Blue john' or 'Derbyshire spar'. The mineral is too soft to preserve a polished surface, being easily scratched, and is now rarely used for ornamental purposes.

Fluorspar is calcium fluoride,  $\text{CaF}_2$ , and until the closing years of the nineteenth century its principal uses were for making hydrofluoric acid and in the manufacture of opalescent, opaque and coloured cathedral glass. Most of

the hydrofluoric acid was then employed for etching patterns on glass, but this is now done largely by the simpler and cheaper method of directing a jet of sand or other abrasive against the glass.

Some fifty years ago it was discovered that fluorspar was superior to limestone as a flux in the basic open-hearth process of making steel, and there was a rapid increase in demand for the mineral. Within recent years about 70% of the total annual production is added as a flux to the furnace charge to give fluidity to the slag and to assist in the removal of such impurities as sulphur and phosphorus. On an average, 7 or 8 lb. of fluorspar is consumed for every ton of open-hearth steel. The mineral is used also as a flux in iron foundries, in the manufacture of electric furnace alloy steels and ferro-alloys, and in the treatment of the ores of gold, silver, copper, lead, and antimony. To a limited extent it is utilized in preparing synthetic cryolite for the extraction of aluminium from bauxite.

Next to steel-making, the largest consumption of the mineral is in the manufacture of hydrofluoric acid and its derivatives, used for making artificial cryolite and aluminium fluoride, for insecticides, preservatives, and dye-stuffs. Thousands of tons are also used in the ceramic industry, and about 3% of world production is consumed in making enamel coatings for baths, kitchen and sanitary wares, etc. Important uses of anhydrous hydrofluoric acid and elemental fluorine have in recent years opened a new field in organic chemistry.

Fluorspar is a glassy, transparent or translucent mineral which may be water-white or range in colour from pale blue to violet, amethyst, deep purple, green, yellow and white. Frequently it is in the form of aggregates of cubic crystals, and the edges of the cubes may be anything from a fraction of an inch to over a foot in length. If a beam of



white light be passed through even colourless fluorspar, a delicate violet colour usually results. This property, fluorescence, received its name from fluorspar, a mineral in which it is well displayed.

When fluorspar is heated to  $1,200^{\circ}$  F. it decrepitates, or flies apart, while such gangue minerals as quartz, pyrite, and galena are hardly affected. Screening the heated product is used in British Columbia and in New Mexico for separation of fluorspar from the gangue minerals.

### *Occurrence and Production*

Most of the fluorspar produced in Great Britain occurs in association with lead and zinc deposits in Carboniferous rocks in Derbyshire and Durham. It is a common gangue mineral in the veins carrying galena and zinc blende in these two counties, where the very extensive old mine-dumps are still being re-treated for the fluorspar they contain. In Durham quartz is a frequent associate of the fluorspar, whereas in Derbyshire barytes often accompanies the mineral. At Castleton in Derbyshire the famous dark blue variety of fluorspar, 'Blue john', was formerly mined for ornamental purposes.

Among the most productive fluorspar deposits in the world are those of Illinois and neighbouring Kentucky in the U.S.A., where the mineral occurs in wide veins and in flat deposits formed by the replacement of Carboniferous limestone, shale, and sandstone. In these two States the mineralizing solutions are considered to have been genetically related to basic and ultra-basic rocks, whereas in Great Britain the fluorspar is believed to have been deposited by hydrothermal mineralizing solutions derived from remote acid igneous sources.

Before the 1914-8 war thousands of tons of fluorspar were exported from Derbyshire to the U.S.A., which now has its

own resources. Most of the principal countries possess adequate supplies of this mineral. During the quinquennial period 1934-8 the average annual world production of fluorspar was 400,000 tons, of which Germany produced 29%; U.S.A. 28%; U.S.S.R. 15%; Great Britain 9%; and France 8%.

In 1952 the chief producing countries were: U.S.A., 298,000 long tons; Mexico, 177,200; Germany (Federal), 154,853; United Kingdom, 75,823; Newfoundland, 74,422; Spain, 72,056; Italy, 57,757; France, 53,000 tons. The average annual world production for the five-year period ended in 1952 was 890,000 tons.

## GOLD

GOLD, long considered to be the 'king of metals', is the first metal mentioned in the Bible (Genesis ii. 11). Man has blessed and cursed, deified and abhorred it, and since his early history has eagerly sought it throughout the world.

Its untarnishable yellow glitter made it since the dawn of history the brilliant ornament *par excellence*; and its relative scarcity and physical properties render it to this day the acknowledged international measure of material values.

The discovery of new goldfields has often induced men to rush madly in search of quick fortunes, and among famous gold rushes of the past century were those to California in 1848; to the 'Comstock Lode' of Nevada in 1858; to Ballarat in Victoria, Australia, in 1851; and to Klondike in Alaska in 1896. Charlie Chaplin's 'Gold Rush' is omitted from this list!

'All that glitters is not gold', and it would be equally true to state that 'the gold that glitters is not all gold', for the pure metal is too soft for use until it is alloyed with other

metals to harden it. Its purity, or 'fineness', is usually expressed in parts of 1,000, so that gold of a fineness of 800 is 8 parts gold and 2 parts not gold; or as a number of carats. Pure gold is 24 carat, but usually the highest degree of fineness of the metal for coinage, rings and other jewellery is 22 carats, which means that 22 parts are gold and 2 parts are of some other metal or metals. For British gold coinage the standard is 22-carat gold, or a fineness of 916.6. A golden sovereign is noticeably redder than pure gold because it is alloyed with 2 parts of copper. The word 'carat' is also applied to precious stones, but in that connexion it is a unit of weight, whereas when applied to gold it is a measure of quality, not quantity.

The principal use of gold is as the standard for monetary systems in the form of coinage, or as ingots of the metal - that is, as bullion. At present well over half of the world's gold is held in the U.S.A., mostly in the form of ingots in well-guarded vaults. Some authorities believe that gold will not resume its dominant role in international economics in future, while others are convinced that it will. It is a significant fact that the metal reacts economically in a direction opposite to other commodities: its production becomes more profitable during periods of economic depression and least profitable during periods of prosperity, especially if accompanied by monetary inflation.

Its next most important use is for ornamentation, especially in jewellery, for which the metal is hardened by alloying it with copper, silver, palladium, or nickel. Small amounts of silver reduce the depth of the yellow colour, and the addition of about 12% palladium, or 25% platinum, or 15% nickel gives 'white gold'. The 'gold stone' of cheap jewellery, it may be added, contains no gold, but thin particles of 'dutch metal', an alloy of copper and zinc

resembling gold in appearance. Gold plating has a variety of decorative uses.

Gold leaf is made by beating the gold by hand. This art of gold-beating is of great antiquity and is referred to by Homer and Pliny. Gold can be beaten to a leaf of only one to two hundred-thousandths of an inch in thickness, although gold leaf is usually about twelve times this thickness. Very thin sheets of gold are translucent and transmit a green light. When used as leaf, the metal is variously alloyed according to the required colour, though for ornamental work exposed to the weather gold of high fineness is employed in virtue of its durability and insusceptibility to tarnish. The external gilding on many public buildings and monuments, such as the Albert Memorial in Kensington Gardens, London, is executed in almost pure gold.

Gold is one of the most ductile of metals. A single ounce of the pure metal can be drawn into a wire fifty miles long. Such wire is used in making gold lace and various fabrics in which the wire is wound over silk threads. There are many minor uses of gold, such as for plating chemical ware for holding certain compounds, for dental filling, spectacles, pen nibs, in some chemical and photographic preparations, and as gold dust for decorative purposes.

### *Occurrence and Production*

Gold as it occurs in nature is very rarely pure; almost invariably it contains silver, and it may contain other metals. Most of the world's gold is obtained from what is termed 'native gold' - that is, from the yellow metallic mineral occurring in the ground, which is predominantly gold. When the silver ratio is high, the mineral alloy is called 'electrum', a pale yellow or almost white metal. In a few localities, gold is found with mercury as natural amalgam.

Next in importance to native gold as a source of the metal come the gold tellurides, chief of which is calaverite,  $(\text{AuAg})\text{Te}_2$ , with 43% gold. Other tellurides of lesser importance are sylvanite and petzite. Gold is also recovered as a by-product from certain base-metal ores such as those of copper, lead, and zinc.

By virtue of its insolubility and high specific gravity, gold occurs unaltered and concentrated in alluvial or placer deposits, and auriferous gravels were the chief sources of the world's gold until recent years, and continue to yield a high percentage (about 20%) of the total metal. The gold in such deposits was derived from the weathering and disintegration of gold-bearing lodes or veins to form eluvial deposits near the outcrops, and alluvial deposits where the material had been transported by streams and deposited at lower levels. The richest gravel, or 'pay dirt' or 'pay lead', commonly occurs towards the bottom of the deposit, frequently near the bed-rock, owing to the high density (gold is about six times as heavy as most rocks) and consequent sinking of the metal in the loose material during deposition. In general, placer gold has a higher degree of fineness than lode gold, and this may be because some of the silver has been leached from the peripheries of the grains of gold. The gold in placers varies in size from mere 'colours' to that of nuggets, some of which have weighed over 200 lb. The 'Welcome Stranger' nugget found in 1869 at Ballarat in Victoria, Australia, weighed 2,268 troy ounces and was valued at £10,000. The largest nugget found at Klondike in the Yukon weighed only 85 troy ounces.

Placer deposits are not always on the surface; some have been formed during early geological times and have subsequently been covered by newer sedimentary, or even by igneous rocks like lava flows. This is the case in Victoria and in California, where the auriferous gravels were found

buried under thick flows of basaltic lava to constitute what are known as 'deep leads'. Many authorities believe that the famous Rand gold deposits of the Transvaal, South Africa, the largest gold-mining field in the world, are old or 'fossil' placers in which the gold in the conglomerate, or 'banket', was transported by surface waters from a geologically ancient mineralized area and subsequently covered by later sediments and folded into an immense synclinal basin. All authorities agree that the conglomerate and the other relevant rocks in the Rand were so transported, but some geologists, including the author, maintain that the gold was deposited later than the conglomerate as the result of infiltration by mineralizing solutions which deposited also the pyrite with which the gold is generally associated, and certain other minerals, like pyrrhotite and cobaltite, which are less restricted in their occurrence in the 'banket' than was formerly believed.

Gold placers may also accumulate as the result of wave and current action on mineralized areas along or near the sea-shore, giving rise to beach or marine placers, such as those of Nome, Alaska, where gold is recovered from the present beach and from raised beaches, now 47 feet and 70 feet above sea level.

The great majority of gold lodes or veins are found within a mile or so of granite, the most favourable areas for such mineralization being near the contact of small granitic intrusions, or stocks, which protrude upwards from an extensive granite mass or batholith, and also near the cupolas of such batholiths. Auriferous quartz veins are among the commonest and most productive kinds of gold deposits. Such veins may be formed originally at great depths under conditions of high temperature and pressure (hypothermal deposits). Those of the famous Kolar gold-field of India; the highly productive Porcupine and parts of

Kirkland Lake districts of Canada; St John del Rey Mine in Brazil; Ashanti and certain other gold mines in the Gold Coast and many others are of this type. The veins in Kolar and St John del Rey are worked at a depth of over 8,000 feet, or over a mile and a half below the surface. Other gold veins which may or may not be quartz veins were formed originally at comparatively shallow depth under relatively low temperature and pressure conditions (epithermal deposits) such as those at Cripple Creek in Colorado, where the gold occurs as a telluride; and the Comstock Lode of Nevada. A third type of gold lodes are those formed under intermediate temperature and pressure conditions (mesothermal deposits), an example of which is the 'Mother Lode' of California.

The gold deposits which are formed under relatively low temperature and pressure conditions usually have a relatively short and merry life. They sometimes yield phenomenally rich values, but, unlike the hypothermal gold lodes, they do not persist to great depth. Many famous bonanzas (rich patches of ore) have been discovered in epithermal deposits, as, for example, a small area in Cripple Creek which produced £4 millions of gold in one year, and at Goldfield in Nevada, U.S.A., where a single truckload of ore weighing less than 50 tons contained gold to the value of £125,000.

In many gold-mines the ore consists mainly of quartz with visible grains of gold scattered through it; in others the metal is enclosed as minute particles in such sulphide minerals as pyrite, arsenopyrite, pyrrhotite or chalcopyrite; in a few fields as gold tellurides with or without native gold; and there are auriferous ores intermediate in character between these three. The particle-size of the gold in different deposits varies considerably, and in some sulphide ores may be so small that none is visible to the naked eye, and it can

be seen only on carefully polished surfaces of the ore when viewed under the microscope with high-power objectives. There are profitable gold-mines in which no miner has ever seen the gold in the ore! In fact, in the chief goldfield of the world – namely, the Rand in the Transvaal, which pro-

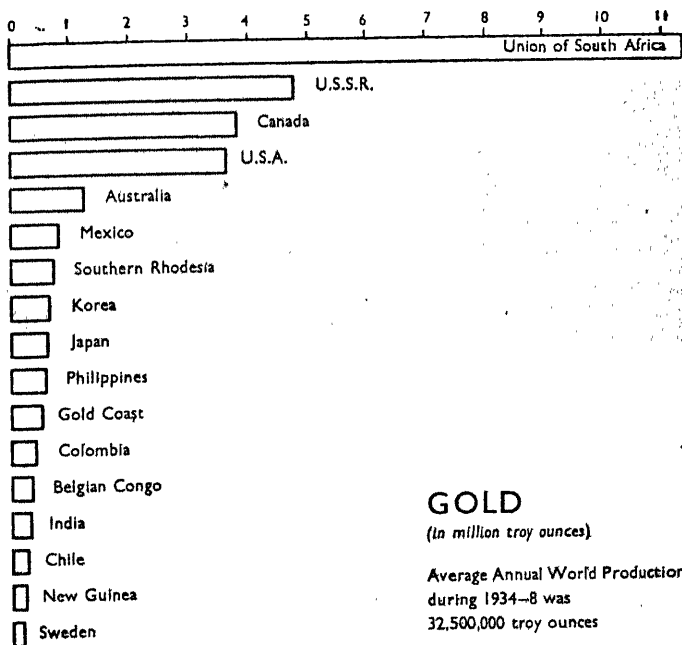


Fig. 10.

duces about a third of the world's gold – it is unusual for the grains of the metal which there occur in the cementing material between the quartz pebbles of the conglomerate to be sufficiently coarse in size to be visible. Yet since the discovery of gold in the Witwatersrand, or Rand, 427,643,558 fine ounces of gold had been produced by the



end of 1947; that is, about £2,500 millions of the metal had been recovered. In May 1954 the total value of the gold had reached £3,100 millions. Some of the mines are now being worked well over a mile and a half below the surface, the three deepest being over 8,700 feet. This gold-field is likely to prove to be one of the largest natural deposits of uranium in the world. The uranium is extracted from the cyanide slime residues and the production is approaching the estimated £30 million worth of uranium annually.

A hundred years ago the annual world output of gold was less than 2 million troy ounces; half a century ago it was 7 million ounces; in 1930 it was 20 million ounces and in 1940 it had reached  $42\frac{1}{2}$  million troy ounces. In 1932 the price of the metal was £4.3 per troy ounce; in 1936 it was £7, and in 1940 it rose to £8.4 and remained at that price until 1949 when it reached £12.4 per troy ounce.

Since 1904 the world's leading producer has been the Union of South Africa, mostly from the Rand Mines in the Transvaal. When the extensive virgin goldfield of the Orange Free State has been developed, the Union's production will increase very considerably. The most spectacular recently exploited goldfields are those in the Philippines, which, between 1930 and 1940, multiplied their total production sixfold and until the Japanese occupation yielded over a million ounces a year. World production of gold since 1940 decreased during World War II to 40,160,000 fine ounces in 1941; 35,400,000 in 1942; 29,300,000 in 1943; 27,070,000 in 1944; and 23,930,000 fine ounces in 1945. During the five years ended in 1952, the average annual production, in terms of the metal, of the chief producing countries was: Union of South Africa, 11,657,748 fine troy ounces; Canada, 4,194,260; U.S.A., 2,048,770; Australia, 904,736; Gold Coast, 685,777; Southern Rhodesia, 507,484; Mexico,

406,816; Colombia, 395,970; Belgian Congo, 338,824; Philippine Republic, 338,812. For this quinquennial period, the average annual world production was 23,620,000 fine troy ounces.

## GRAPHITE

THE ubiquitous lead pencil has no lead in it at all! The substance that comes in contact with the writing paper is graphite mixed with about an equal amount of a special fine clay and moulded into shape and baked at a temperature of 1,500–2,000° F. Graphite is derived from the Greek word 'grapho' meaning 'I write', and, because in early days it was mistaken for lead, it was called plumbago and blacklead. Approximately only 12% of the world's graphite is used in pencils and crayons, whereas 60% is employed in foundries and in making graphite crucibles for metallurgical purposes.

When metal castings are made, the pattern is buried in moulding sand, which retains its shape after removal of the pattern. The mould surface is then coated with graphite, often mixed with talc, which not only gives it a smooth surface, but also prevents the casting from sticking to the mould.

Graphite crucibles, made by firing a mixture of graphite with clay and sand, are used for melting brass and crucible steel. The crucibles are of various sizes, and the largest may hold more than half a ton of metal. Thirty years ago more than half the world's graphite production was so employed, but the advent of the electric furnace largely displaced the use of graphite crucibles, as is shown by the fact that, whereas 55% of the production in 1913 was consumed in crucibles, only 18% was thus employed in 1933. In the last

few years, however, graphite crucibles are again gaining favour.

Finely pulverized graphite finds extensive use as a lubricant, either alone or more commonly with grease, oil or water. It is used alone for lubricating textile machines and in pianos and organs, where oil or grease would be objectionable; and with oil or grease for heavy machinery.

Considerable quantities of graphite, usually not of high quality, are utilized in graphite paints and pigments for protecting metal surfaces from the corroding effect of smoke, sulphurous gases, acids and alkalies. Stove-polish is a familiar example. Among minor uses are as electrodes, brushes for dynamos and motors, and in dry batteries and glazing powder.

Graphite, which is a very soft, black and opaque mineral, is a near relative of diamond, the hardest of all minerals. Both are chemically the same, being different forms of carbon, their markedly contrasting physical properties being due to their individual crystalline structure.

For trade purposes natural graphite is divided into two classes, 'crystalline' and 'amorphous'. The so-called 'amorphous' variety is not truly amorphous, but is finer grained than the crystalline, and this is their only real difference. Within recent years the demand for the crystalline variety has decreased, owing largely to the declining use of graphite crucibles, and increasing quantities of the so-called amorphous kind are now being utilized. A recent and increasing use of graphite is as a 'moderator' in slowing down the action of neutrons of uranium. Large blocks of pure graphite are used in the atomic pile, or primary reactor (see page 212).

### *Occurrence and Production*

Graphite is found principally in metamorphic rocks such

as gneisses, schists and metamorphosed limestones which have been subjected to considerable heat and pressure by natural agencies; also in pegmatite and quartz veins, which often have the appearance of being the infillings of open fissures. In the gneisses and schists the graphite usually occurs as small flakes orientated parallel to the foliation planes of the rock.

The source of the carbon in some cases was probably the organic carbonaceous matter in the sedimentary rocks, which were later converted by intense heat and pressure into gneisses or schists, but, in the case of some metamorphosed limestones or marbles, the carbon may have been formed during the dissociation of carbonates such as  $\text{CaCO}_3$  by intense heat and pressure. The graphite deposits of Madagascar, Germany and Korea (Chosen) occur as disseminations and as veins and pockets in gneisses and schists, whilst the Canadian deposits include also those in metamorphosed limestone and in pegmatite veins. The important Ceylon graphites are in definite fissure veins, up to 6 feet in width, traversing ancient gneisses. These have been worked to a depth of over 600 feet with little change in the graphite content of the lode material. These vein deposits are generally interpreted as of igneous origin, the carbon being possibly formed by gaseous emanations of carbon compounds. In Mexico large quantities of amorphous graphite have been won from coal-beds which have been altered to graphite by heat derived from igneous dykes.

Complete production figures of graphite have not been available since 1935, when the annual world output was 210,000 tons, but there is evidence that the total production has since increased. In 1935 the U.S.S.R. yielded 39% of the world production, Chosen (Korea) 21%, Germany 10%, Austria 9%, Ceylon 7%, Madagascar 5%, and Mexico 3%.

The total world production for 1944 was estimated to be 300,000 tons, a third of which was produced in Korea and Japan for war-time needs. In 1952 the chief producing countries were: Mexico, 23,772 long tons; Austria, 19,500; Madagascar, 18,186; Korea, 14,822; Ceylon, 7,660; U.S.A. 5,005 tons. The average annual world production for the five years ended in 1952 was 140,000 tons.

Formerly for many years Ceylon and Madagascar dominated the graphite market, and they still have a virtual monopoly of high-grade crystalline graphite for crucibles. Korea and Mexico produce mainly amorphous graphite.

## GYPSUM AND ANHYDRITE

MODELLING clay and hardening it by burning was one of man's earliest means of permanent expression, but in later years 'plaster of Paris', made from the mineral, gypsum, proved a more satisfactory medium. It was used originally for decorations in relief and for temporary buildings like those of the White City at Shepherd's Bush, London, which were constructed largely of plaster of Paris; but its applications are now manifold.

When heated to a temperature of from  $110^{\circ}\text{C.}$  to  $120^{\circ}\text{C.}$ , gypsum,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , loses more than half of its water of crystallization and is converted to the white powder, plaster of Paris, which is capable of absorbing water and setting to a comparatively hard mass.

It is after conversion to plaster of Paris that gypsum has its main uses, but the uncooked or uncalcined mineral is employed in making mineral white ('*terra alba*'), as a filler in paper and cotton, for dusting underground passages in collieries, in paints, and is being increasingly employed in

Portland cement to retard and control the time of setting. Gypsum is utilized also as a soil fertilizer (formerly its chief use), as a flux in the smelting of nickel ores, for improving or 'Burtonizing' water for beer-making, and when in white, massive, and compact form it is known as alabaster and used for ornamental purposes. In recent years it is much used as an insulator against heat and cold in modern homes, and acoustical gypsum plasters are now a feature in the construction of auditoriums and rooms to reduce excessive noises.

Plaster of Paris is employed extensively in the building trade in the form of hardwall plasters, sheets, plasterboard and wallboard, and for stucco work. The addition of alum, or other salt, to gypsum calcined at high temperature produces quick-setting cements such as Keene's cement and Parian. It retards the setting of cement, and about 3% is added to Portland cement for this purpose.

Thousands of tons of plaster of Paris are used annually in British and other potteries for making moulds in which cups, jugs, basins and other ware are shaped by casting or otherwise. The liquid clay mixture is poured into the moulds, and, when the required thickness of clay has settled in the mould consequent on the absorption of the water from the clay mixture, the remaining liquid is poured off. After drying, the shaped ware contracts, is easily freed from the mould, and, after sponging, is then ready to be fired. Modellers, dentists, marble-workers and lithographers also use plaster of Paris.

#### ANHYDRITE

Twenty years ago anhydrite,  $\text{CaSO}_4$ , had practically no industrial application, but Imperial Chemical Industries in this country discovered new uses for it, with the result that

at Billingham in County Durham the anhydrite in the deposit occurring there is treated with synthetic ammonia, made from nitrogen of the atmosphere, to form ammonium sulphate, used as a fertilizer. Much of the anhydrite is also reduced with coke to form sulphur dioxide for the manufacture of sulphuric acid. The calcium carbonate formed during one of the processes is treated with nitrogen to form nitro-chalk, also used as a fertilizer.

### *Occurrence and Production of Gypsum and Anhydrite*

Commercial deposits of gypsum and anhydrite usually occur in the form of beds in sedimentary rocks. They were deposited as saline residues precipitated during the evaporation of enclosed basins of sea-water, with the result that rock-salt is frequently associated with the two minerals. Under normal conditions of evaporation of sea-water in dry climates there is successive precipitation of calcium and magnesium carbonate (which may form limestone), calcium sulphate (which may form gypsum and anhydrite), rock salt, and, finally, of potassium and of magnesium salts (which may form carnallite, kieserite, polyhalite and other salts). Such a sequence of deposition characterizes the famous Stassfurt deposits in Germany. In the United Kingdom this sequence is incomplete, but the rock salt beds in Cheshire and the gypsum and anhydrite deposits of the North of England owe their origin to evaporation of enclosed sea-basins during the arid conditions which obtained in Permian and Triassic times. Experiments have shown that the evaporation of sea-water at temperatures below  $25^{\circ}\text{C}$ . leads to the formation of gypsum and that at higher temperatures anhydrite is precipitated. It may be, therefore, that alternating beds of gypsum and anhydrite may, at least in part, result from past seasonal variations of

temperature at the time of deposition. Such beds may attain thicknesses of several hundreds of feet. In some cases anhydrite has changed by hydration to gypsum, and gypsum, by loss of water of crystallization, to anhydrite.

Gypsum is also formed in nature by the interaction of sulphuric acid or other sulphate compounds with calcium carbonate or limestone. Thus the sulphuric acid resulting from the decomposition of iron pyrites or other metallic sulphides may attack shells embedded in clays to produce well-formed crystals of transparent gypsum, named selenite, such as are found in London Clay and Oxford Clay.

Sulphuretted waters in volcanic regions may become oxidized to sulphuric acid as they approach the surface, and by interaction with limestone may also produce workable deposits of gypsum.

Within recent years the annual world output of gypsum has exceeded 10 million tons. The deposits are so widely distributed and of such ample size that most countries are able to provide their requirements from domestic sources. Since 1936 the production of gypsum and anhydrite in England has been over a million tons a year. In foreign countries the output of gypsum greatly exceeds that of anhydrite.

In 1952, Great Britain produced 1,358,400 long tons of gypsum and 1,036,300 tons of anhydrite. The other chief producing countries of gypsum were: U.S.A., 7,205,428 tons; Canada, 3,173,140; Germany (Federal), 753,000; Spain, 670,300; India, 410,715; Australia, 351,678; Japan, 197,475; Union of South Africa, 144,688; Cyprus, 110,000; Austria, 104,130.

## ICELAND SPAR

ICELAND spar is the name given to the pure, transparent and colourless variety of calcite,  $\text{CaCO}_3$ , when it is so



flawless that it can be used for polarizing light in petrological microscopes, saccharimeters, photometers and other optical instruments. Formerly the only source of the mineral was Iceland, hence its name, but that country is no longer the most important source.

If a crystal of Iceland spar is placed over a black dot made on white paper and viewed from above, two dots will appear. This is because the mineral has strong double refraction, and this property is utilized in the nicol prisms of certain optical instruments for transforming ordinary light into plane-polarized light. No other mineral or artificial substance is known which can be substituted satisfactorily for all the optical uses of Iceland spar, although in recent years 'polaroid' has replaced it for some purposes.

### *Occurrence and Production*

The spar deposit in Iceland is embedded in clays within cavities or pockets in basaltic lavas. When first discovered the main cavity was lined with very large pure crystals measuring up to 3 feet in diameter, and was later quarried to a depth of more than 50 feet. Iceland has produced most of the world's optical calcite, but since 1918 the quality has deteriorated, and the world demand has been supplied mainly from the Kenhardt district of Cape Province, South Africa, where it is also found embedded in soft clays which fill cavities in basic igneous rocks. Within the last decade Spain has exported some good-quality spar, and in 1940 production was started near Taos, in New Mexico, U.S.A.

No production or consumption figures for Iceland spar are available. The demand is intermittent, but it is estimated that, on an average, about 300 lb. a year are used in the U.S.A. and an annual world total in the neighbourhood of 1,200 lb.

## IODINE

TINCTURE of iodine is one of the best known antiseptics, but far more iodine is consumed in human and animal food than as an antiseptic. It is quite common practice to add small amounts of potassium iodide to the common salt used for seasoning, to animal foodstuffs, and in certain districts to the drinking-water supply as a preventive against goitre. Within recent years it has also been applied to a small extent as a soil fertilizer.

Small quantities of iodine are used in preparing various organic compounds, including dyes, and as reagents in the chemical laboratory. Its most important technical application, however, is in making sensitizing solutions for photographic films, plates and paper.

*Occurrence and Production*

Most of the world's supply of iodine is obtained as a by-product from the nitrate region of Chile. The crude nitrate, or caliche (see p. 145), contains about 1 lb. of iodine, chiefly as iodates, to every ton of caliche.

Certain varieties of seaweed have supplied considerable amounts of iodine, which is recovered from the ash, or 'kelp', obtained by burning the weed collected along the storm-swept coasts of Ireland, Scotland, France, Norway, Russia and Japan.

In the U.S.A., Java, and Italy, brine-wells yield small but valuable supplies of iodine, the American output being obtained from oil-well brines in California and Louisiana.

Over a long period of years the world output of iodine has averaged approximately 800 tons annually, of which Chile produces about 70%. U.S.A. and Java are important producers, and then follow, in decreasing order of production, France, Japan, Italy, and Great Britain.

## IRON

IRON is the most indispensable of all metals, and can be regarded as the framework of modern industry. Man has been skilled in its use for more than 3,000 years, and if all the iron now in service were suddenly to be removed, civilization as at present understood would suffer a fundamental change.

For every ton of the earth's crust there is on average a hundredweight of iron, and next to aluminium (which is an essential constituent in clays and most rocks) it is the most prevalent metal of all. The various shades of yellow, brown, red and green of clays, sands and other rocks owe their colour mainly to oxides and hydroxides of iron, and it has been well said that 'iron is the chief pigment in nature's colour-box'.

In spite of the fact that iron-bearing minerals occur so abundantly, and that iron can be produced from some of them by heating with charcoal, it was not used by man until long after such metals as copper and its alloy, bronze, which gave name to the Bronze Age which preceded the Iron Age. The reasons for this are interesting. Pure iron is too soft for use in implements, and it took man a long time to control the carbon content of iron to harden it; and until engines and railways were built there was no great need for iron. It was not until 500 years ago that cast iron was first made in furnaces where some of the carbon combined with the iron. From the fourteenth to the seventeenth century Sussex was the great iron-smelting district of England; the great forests which then covered the Weald were felled to provide charcoal for the furnaces. The guns that battered the Spanish Armada and the railings that still stand round parts of St Paul's Cathedral were cast from Sussex iron.

The great ascendancy of iron dates from the development of steam power, and during the last few years the world production of pig iron has exceeded 100 million tons annually. Pig iron is made in a blast-furnace, and for every ton produced it usually requires about two tons of ore, half a ton of limestone, one ton of coke, and four and a half tons of air. The pig iron can then be made into cast iron in a foundry, into wrought iron in a puddling mill, or into steel in an open-hearth furnace or Bessemer converter.

Cast iron is brittle, but fairly easy to melt and to pour into moulds; on account of its resistance to heat it is commonly used in stoves, fireplaces, kitchen ranges and so forth; and because it rusts less easily than forged iron and steel, it is employed for water-pipes, gutters, troughs and other water-containing vessels. Heavy castings for engines and large machine-tools are often made of cast iron.

Wrought iron can be forged hot, drawn into wire, and bent when cold without cracking. Its toughness, resistance to shock and corrosion and its other properties render it suitable for pipes, chains, nails, hinges, bolts and nuts, horseshoes, and blacksmith's bar iron.

Before 1870 cast iron and wrought iron were the principal forms of the material employed for construction purposes, but iron in another form was fast asserting its superiority over both for some important uses. In 1860 the Bessemer process was successfully established in Sheffield, and a mild steel was produced which was much cheaper and stronger than wrought iron. In the Bessemer process, liquid pig iron, low in sulphur and phosphorus, is poured into a barrel-shaped converter lined with siliceous materials. Air is then blown through the liquid, with the result that the oxygen in the air combines with the carbon, silicon, and other impurities of the pig iron to form a surface slag which is poured away after the carbon has been burnt off.

A certain amount of spiegel – that is, carbon and manganese – is then added to eliminate oxygen from the steel and to leave a definite quantity of carbon and manganese as part of the finished steel.

Steel contains a definite amount of carbon, usually less than 1%, with a maximum of 1.6%.

In the basic Bessemer converter the containers or shells are lined with magnesite or dolomite, and the ore thus treated has generally a high content, say 2% or so, of phosphorus. This process is still the dominant practice in treating pig iron produced from the famous Lorraine ores, but is not popular in England or the U.S.A. for various reasons. The slag from the basic process (basic slag) is a valuable fertilizer, as it may contain up to 20% soluble phosphoric acid.

The open-hearth process, developed in England by Sir William Siemens, has ousted the Bessemer process in most countries and is the one now practised most extensively. By this process steel can be produced from almost any kind of iron ore, the carbon content of the steel can be regulated with great precision, and larger quantities of steel per charge can be made than with the Bessemer process. In its essentials, the open-hearth method consists in burning out carbon from the pig iron until tests indicate that the requisite amount of carbon remains. The refractory lining materials in the acid hearth are siliceous, whereas in the basic hearth they consist of magnesite or dolomite. Low-phosphorus ores are treated in the acid open-hearth, and those high in phosphorus in the basic open-hearth.

The electric furnace is now employed for making high-quality steels, such as special alloy steels, crucible steels, ferro-manganese steels and others. Most of these furnaces are of small capacity, but are employed for super-refining the molten metal from the open-hearth furnace.

During the last three decades there has been increasing demand for ferro-alloys of many kinds for particular uses. Manganese and small amounts of nickel, cobalt, tungsten, molybdenum, vanadium, and other metals are added to steel to give it special properties, such as hardness, anti-corrosion, high tensile strength, increased elasticity and magnetism and other qualities.

It is well beyond the compass of this book to enumerate the long list of uses of steel, many of which, moreover, are common knowledge. Railways and tramways in the different countries account for 200 million tons of steel, not to mention the millions of tons employed in ships, bridges, buildings, tanks, guns, and innumerable other ways.

World production of steel ingots and castings in 1913 was 75 million tons; in 1929 it was 118 million; in 1937 it reached 132 million, and from the latest figures available - namely for 1940 - it was 143 million tons.

### *Occurrence of Iron Ore*

Although the list of iron-bearing minerals is a very long one, four minerals only are important sources of the metal. These are: magnetite,  $\text{Fe}_3\text{O}_4$ , with theoretically 72% iron, and sometimes referred to as black or 'magnetic ore'; hematite,  $\text{Fe}_2\text{O}_3$ , a red ore with 70% iron; limonite,  $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ , a yellowish-brown ore (with varying amounts of water of composition) and containing 60% iron; and lastly, siderite,  $\text{FeCO}_3$ , sometimes known as chalybite or spathic iron ore, with theoretically 48% iron, and of various colours, chiefly from ash-grey to brown. It should be added, however, that certain important iron deposits, such as those worked in the Midlands in this country and parts of France, although popularly regarded as siderite or carbonate iron ores, are composed to some extent of greenish hydrous iron silicates such as chamosite and greenalite.

The theoretical percentages of iron in the first four minerals named above are never attained in ore deposits of these minerals. Rich deposits of magnetite may contain up to 68% iron, such as those at Kiruna and Gellivare in Northern Sweden. When the Baltic is frozen, these ores are shipped from Narvik in Norway. Under favourable conditions many iron ore deposits carrying as little as 25% iron can be worked profitably. The common impurities in iron ore are silica (frequently as quartz), aluminium (in clay), calcium and magnesium (in magnesian limestone) and manganese, titanium, sulphur, phosphorus, and arsenic. The titanium and manganese content may enhance the value of the ore, but sulphur, phosphorus and arsenic are undesirable impurities, though they can be removed by suitable metallurgical treatment.

MAGNETITE is readily detected by means of a hand magnet, to which it is strongly attracted, and by its black colour. One variety is known as lodestone, because it exhibits natural magnetic polarity. Indeed, the earliest form of mariners' compass consisted of a splinter of magnetite floating on a bowl of water. Magnetite is found as sparingly scattered particles in most igneous rocks and in many sedimentary rocks, but occurrences of it in workable quantities are confined to a few regions, where, however, it forms large and very important sources of iron.

The most famous of all magnetite deposits are those at Kiruna and Gellivare in Northern Sweden, where the ore at Kiruna outcrops on top of a ridge and is worked extensively in large open quarries. It has been proved that this deposit has ore reserves amounting to over 1,000 million tons. The ore-body occurs between a hanging wall of syenite porphyry and a footwall of quartz porphyry; and it probably originated as the result of magmatic differentiation in depth, resulting in the segregation of the magnetite

and its subsequent injection as a molten sheet, which then consolidated to its present form. In spite of the richness of these Swedish deposits they were not worked for many years after their discovery on account of their high phosphorus content. It was not until the invention in this country of the 'Thomas process' of treatment that the objectionable phosphorus could be removed successfully.

Some important magnetite deposits in the U.S.A., the U.S.S.R. and elsewhere have been formed as the result of the conversion of sedimentary ironstones into that mineral by metamorphic agencies.

HEMATITE, named after the Greek word meaning 'blood', in allusion to the red colour of the mineral, occurs in different forms. When in good crystals with adamantine lustre it is called 'specularite' or 'specular ore' ('looking-glass ore'); when in thin plates or scales it is known as 'micaceous hematite'; and when in large kidney form masses it is frequently referred to as 'kidney ore'. It also occurs as octahedra of martite, resulting from the alteration of magnetite.

In Cumberland and the Furness district of north Lancashire ore-bodies of hematite occur as large irregular masses, as 'flats' related to the stratification of the enclosing rocks, and in pockets and hollows, all within limestone beds of Carboniferous age. The ore-bodies were formed mainly by replacement of the limestone by hot ascending mineralizing solutions, but in some of these deposits the iron is stated to have been derived from red ferruginous sandstone of Triassic age which overlies the ore-bearing limestone.

The famous hematite deposits of the 'iron ranges' near Lake Superior are worked in the most productive iron mines in the world, the chief of them being in Minnesota, although similar deposits are worked also on a large scale in Michigan. In 1940 the Lake Superior iron field yielded



more than 60 million tons of ore containing from 50% to 60% iron. This tonnage is equivalent to 84% of the whole output of iron ore in the U.S.A., and is about 28% of the world total production for that year. Many authorities support a theory of sedimentary origin for the Lake Superior hematite deposits, while others equally eminent believe that the iron and the silica (to form the cherts with which ore is associated) were carried upwards by magmatic waters from an igneous source and deposited on an old sea-floor, the silica as chert and the iron originally as a carbonate which was later oxidized to hematite. Much of the silica has been leached away, thus converting the original low-grade deposits into workable ore-bodies.

The largest deposits in the U.S.S.R., those of Krivoi Rog in the Ukraine, consist largely of martite, the cubic form of hematite. The mines in that field produced in 1938 more than 20 million tons of ore. It is considered that the iron was derived from a ferruginous mantle overlying an old land surface and that the iron was transported in colloidal form by streams into a vast lake-basin, where it was originally precipitated as the carbonate and silicate of iron.

Spain has important hematite deposits at Bilbao. The primary ore was probably deposited as siderite replacements in limestone, and, where not oxidized into hematite, parts of the deposits are in their original carbonate form. Brazil, Cuba and other countries also have workable deposits of hematite.

A recently discovered hematite field in Canada is of unusual interest. It is on the Quebec-Labrador boundary and over 600 million tons of ore are known to occur there. A 360 mile rail connexion is nearing completion to transport the ore to the north bank of the St. Lawrence.

LIMONITE, the yellowish to brown hydrated oxide of iron, is the result of decomposition of other iron-bearing

minerals, and is usually the predominating ore mineral in the iron caps, so common on the outcrops of sulphidic ore-bodies, particularly of those containing much iron pyrites. The various shades of yellows and browns of clays, sands, and other rocks are due mainly to the presence of limonite.

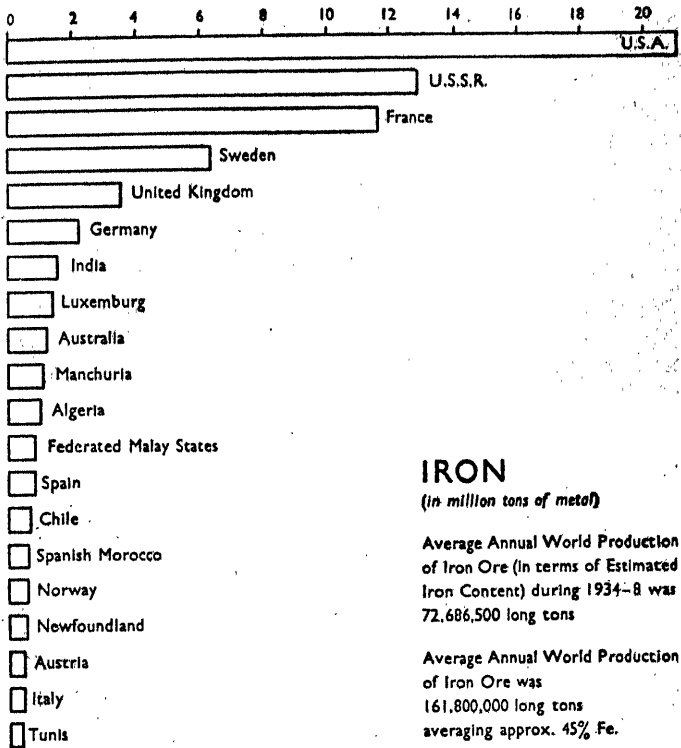


Fig. 11.

Sometimes the iron is carried in solution in water to form limonitic 'bog iron ore' in swamps or shallow lakes where minute organisms, such as bacteria, help in the precipitation of the limonite.

The most productive of the limonitic deposits of the world are the great 'minette' iron ores of Alsace-Lorraine, which, in 1937, produced 35 million tons of ore containing an average of 35% iron with 1.7% phosphorus. The iron-bearing formation includes several beds, all of Jurassic age, and the ore is oolitic, with myriads of tiny egg-shaped grains of siderite and hematite which have been oxidized and hydrated to limonite, now the dominant mineral in the deposits. The ore-bodies are unquestionably of sedimentary origin, the iron being derived from old adjacent land areas and deposited in relatively shallow water.

Ores containing the carbonate of iron, **SIDERITE**, are of many varieties. The impure form of the mineral found as nodules and discontinuous beds in the Coal Measures of many countries is known as 'clay-ironstone', and when it contains sufficient coaly matter to enable it to be smelted without additional fuel it is often called 'blackband ironstone'. Formerly these two varieties of sideritic ore were important sources of iron in this country, but during recent years they have been worked at only a few places.

The most productive siderite deposits in England are the Jurassic oolitic iron ores, which stretch southwards from Yorkshire through Lincolnshire, Leicestershire and Rutland into Northamptonshire. The chief mines are in Cleveland, Yorkshire, and in Northamptonshire. The ores are low grade, averaging less than 30% of iron and containing about 1% phosphorus. They contribute more than 90% of the whole production of iron ore in the United Kingdom, most of the remainder being hematite ores from Cumberland, Westmorland, and the Furness district of Lancashire.

The common type of these Jurassic ores is chamositic mudstones and chamositic and sideritic mudstones. They are oolitic, and it is believed that they are of marine origin. The unweathered ore is often greenish in colour, owing to

the presence of iron silicate, but where oxidized it is yellowish to brownish as the result of its conversion to hydrated oxide of iron – that is, to limonite. Somewhat similar oolitic hematite-chamosite-siderite ores occur in flat-lying beds in Ordovician rocks in Newfoundland, where they are mined on a large scale, in places for a distance of 2 miles under the sea. A large ore-body, said to contain 100 million tons of siderite, is being worked at Helen Mine, north-east of Lake Superior, within the Canadian boundary. Many iron ores which now consist of hematite and limonite or magnetite, such as those of the Lake Superior district of the U.S.A. and of the Russian Ukraine, contained originally large amounts of siderite. In many metalliferous veins siderite occurs as a prominent gangue mineral.

### *Production*

The accompanying diagram (Fig. 11) shows the average annual world production of iron ore (in terms of estimated content of iron) during 1934–8. Within this quinquennial period the peak year was 1937, when there was a production of 213 million long tons of iron ore with an estimated iron content of 97 million tons, of which the U.S.A. provided nearly 38%. In that year the production of pig iron and ferro-alloys was 102,500,000 tons and that of steel ingots and castings 132,300,000 tons. The steel output was considerably more than that of pig iron (and has been so since 1914), owing chiefly to the amount of scrap iron incorporated in the steel charge. The geographical distribution of the chief iron fields is shown in Fig. 30.

During the five years ended in 1952, the average annual production, in terms of the iron content, of the chief producing countries was: U.S.A., 50,000,000 long tons; France, 10,485,000; Sweden, 8,722,000; United Kingdom, 4,228,000; Germany, 2,924,000; India, 2,002,000; Canada,

1,973,000; Chile, 1,667,000; Australia, 1,373,000; Algeria, 1,347,000; Luxembourg, 1,323,000. For this quinquennial period, the average annual world production was 253,000,000 long tons.

## LEAD

LEAD does not occur in nature as a metal, but is so readily reduced from its ores, and the resulting soft material is so easily shaped into vessels, that it was among the earliest metals used by man. The hanging gardens of Babylon had lead pans to hold plants, and the lead mines of Spain supplied the Romans with the metal they used extensively as lead pipe to convey water. Lead pipes 2,000 years old are still almost 'as good as new'. Alloyed with tin and antimony, lead proved the most satisfactory substance for casting type when movable type was invented in Europe in the fifteenth century, for it made a sharp impression, and when broken could be easily recast. Antimonial lead is now the chief type-metal.

The expression 'heavy as lead' epitomizes the popular conception of the metal, whereas, in fact, it is actually much lighter in weight than gold, platinum, or mercury.

A good idea of the present chief uses of lead is obtained from the consumption figures of the metal in the U.S.A. for the year 1940, when that country, the chief user, employed 700,000 long tons of metallic lead for industrial purposes. Storage batteries took 28% of the total; cable covering 14%; white lead (for paint, etc.) 9%; building 9%; red lead and litharge 8%; ammunition 8%; solder 3%; foil 3%; caulking 2%; type-metal 2%; bearing-metal 2%; miscellaneous uses, includingterne plate, castings, lead tetraethyl for tempering petrol (anti-knock petrol)

12%. Formerly, as much lead was used in cable covering as in batteries, and it has been stated that 'no less than 94% of the 80 million miles of wire of the Bell Telephone system of the U.S.A. is enclosed in lead cable coverings'.

Lead for storage batteries and for cables is hardened by the addition of small amounts of antimony, and that in old batteries is easily recovered for use in new ones. In building construction, the metal is employed for roofing, for cornices, drainage and sewer pipes, tank linings, electrical wiring, etc. Because of its weight and malleability it is utilized in yacht keels, for packing joints, as plumb-bobs, and sinkers in diving suits. For ammunition purposes, as bullets and shrapnel balls and so forth, 'hard lead' or 'antimonial lead', an alloy of lead with 4-12% of antimony, is employed; and with less antimony, from 1% to 4%, it is made into sheet, foil and collapsible tubes. Soft solder, used chiefly for soldering tinplate and lead pipes, is an alloy of lead and tin which melts at about 350° F. and remains in a plastic state sufficiently long to enable the plumber to 'wipe the joint'. This is because the lead in the solder hardens before the tin, which remains molten between the lead particles until the whole mass becomes rigid. Alloys of lead with tin and antimony make serviceable bearing metals where the load is not great nor the speed high.

The three chief compounds of lead are 'white lead', 'red lead' and litharge. 'White lead' is basic lead carbonate, and is widely used as the basis of paint because of its opacity, preservative properties and durability. In some countries its utilization in paint is prohibited to avoid the danger of lead poisoning to the painters. Lithopone (p. 43), zinc oxide (p. 221), barytes (p. 44), titanium oxide (p. 199), and cellulose lacquers are to a considerable extent now replacing white lead in paints.

Several grades of 'red lead' are used, especially as a protective coating on ferrous metals exposed to the atmosphere, and to a lesser extent in glass-making and the manufacture of varnishes. Litharge, an oxide of lead, is also employed in making glass and varnishes and, in addition, in the vulcanization of rubber and in pottery glazes. A variety of red lead, 'orange mineral', is utilized in making red paint, printing ink and dipping paint.

Lead salts have a variety of minor commercial applications, such as lead nitrate for dyeing and printing calico, lead arsenate for insecticides, lead acetate in medicine; and in recent years there has been a rapid increase in the use of lead tetraethyl for tempering petrol.

### *Occurrence and Production*

The sulphide of lead, galena,  $\text{PbS}$ , is by far the most important source of the world's lead. This mineral almost invariably contains some silver, and often in sufficient quantities for profitable extraction. In fact, most of the world's silver is obtained as a by-product from lead ores.

In the upper parts of lead deposits it is frequently the case, particularly in hot and dry climates, that the primary or original mineral, galena, has undergone oxidation to form lead oxy-salts, the chief of which is cerussite,  $\text{PbCO}_3$ , and to a much lesser extent, the sulphate, anglesite,  $\text{PbSO}_4$ . In some of the chief lead fields, such as at Broken Hill in New South Wales and the Coeur d'Alene district of Idaho, cerussite constituted an important ore mineral in the upper workings.

Although lead deposits may contain no zinc ore, and zinc deposits no lead ore, nevertheless the lead and zinc minerals are frequently present in workable quantities in the same mine. Galena and zinc blende, or sphalerite, as the latter is also termed, are so intimately associated that

in only few parts of the world do commercial deposits of zinc occur without galena, although the reverse is not equally the case.

Most lead deposits are in sedimentary rocks in the form of lodes or veins, as replacements and disseminations in limestones and dolomites, and in a few cases as residual deposits resulting from the solution of carbonate rocks.

Well-defined, frequently steeply-dipping, vein deposits of lead (usually with zinc ore) are common in many parts of the world, and in the past were worked in this country in the Pennines and in North Wales, and now at Greenside

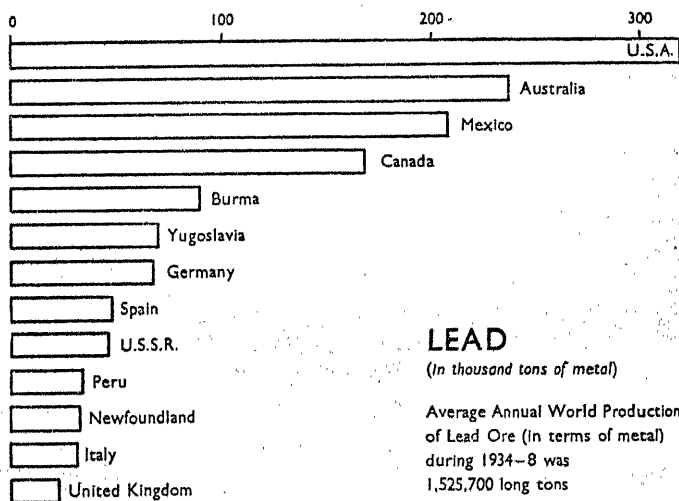


Fig. 12.

Mine in Cumberland. The lead was deposited as galena by hot mineralizing solutions which emanated from an igneous source which may be near or, as in parts of this country, a considerable distance from the ore-bodies. These



solutions, when traversing limestone rocks which they can easily replace, may follow the bedding planes to form almost horizontal or low-dipping ore-bodies, such as the 'flats' which formerly yielded large tonnages of galena in Derbyshire, County Durham and other parts of the United Kingdom, and in other countries.

In the famous Leadville district of Colorado, lead-zinc ores occur as replacements in limestones where the ascending mineralizing solutions were trapped beneath a dense mass of porphyry to form the main ore-bodies. It is often the case in other countries that the chief ore-bodies in limestones or dolomites are found below an impervious bed of shale or other rocks which have blanketed the ascending solutions.

There has been considerable controversy as to the origin of the lead deposits in Missouri and the Tri-States in the U.S.A., which are among the largest lead-producing fields of the world. Some authorities maintain that the ore-bodies were formed by downward percolation of waters which had dissolved and concentrated the lead from the overlying rocks, but it would now appear that in recent years further evidence favours the theory that in these lead fields, as in most of the others throughout the world, the ore-bodies were deposited from ascending hot mineralizing solutions. In some fields, as in Broken Hill in N.S. Wales, Sullivan Mine in British Columbia (the largest lead-zinc mine in the world), Bawdwin Mines in Burma and a few others, the temperature conditions obtaining during the deposition of the ore were considerably higher than in the great majority of cases.

In 1938 the total world production of lead ore, in terms of metal, was 1,780,000 long tons. The leading producers (see Fig. 12) were the U.S.A. with 19%, Mexico 16%, Australia 15%, Canada 11%, Germany 5%, Burma 5%,

Yugoslavia (mostly from Trepca Mines) 5%, the remaining 24% from mines in almost every other country in the world, so ubiquitous is lead mineralization.

During the five years ended in 1952, the average annual production, in terms of metal, of the chief producing countries was: U.S.A., 357,763 long tons; Australia, 221,492; Mexico, 221,182; U.S.S.R., 173,000; Canada, 150,115; Yugoslavia, 73,180; Peru, 68,510; French Morocco, 52,224; Germany (Federal), 41,796; South-West Africa, 38,925; Spain, 35,778; Italy, 35,680.

For this quinquennial period, the average annual world production, in terms of metal, was 1,642,600 long tons.

The geographical distribution of the chief lead fields is shown in Fig. 27.

## LITHIUM

THE most spectacular use of lithium is in the form of lithium chloride for imparting a vivid crimson flame in fireworks and signal lights; and lithia water had once a high reputation, largely spurious according to many authorities, for assisting in the elimination of uric acid in gout and rheumatoid afflictions.

Owing to its hygroscopic, non-volatile and non-toxic properties, lithium chloride is now employed to an increasing extent for dehumidifying air for air-conditioning, and as an industrial drying reagent. The chloride and fluoride are used as fluxes in welding, especially for aluminium; and lithium hydroxide is employed in mercerizing cellulose for rayon. The bromide and iodide have limited use in photography.

The lithium-bearing mica, lepidolite, is used in the form in which it occurs in nature, for glass-making and in cera-

mics. The lithium and fluorine in that mineral have valuable fluxing action, thus facilitating the melting of glass and endowing the product with a lower coefficient of expansion, thereby lessening the danger of breakage on sudden changes of temperature. It also enhances the strength of glass, glazes and enamels. When added to the melt in large quantities, lepidolite acts as an opacifier in opalescent and white glass such as is widely used for table-tops, ointment jars and so forth.

Metallic lithium has been used in small quantities during the last decade for making certain ferrous and non-ferrous alloys, to which it imparts additional hardness, toughness and tensile strength, as in bearing-metal alloys, copper electrodes and lead cable-sheaths. It also acts as a degasifier, deoxidizer, desulphurizer and general purifying agent in certain alloys. Lastly, it has recently been used to develop a neutral atmosphere in furnaces employed for heat-treatment.

### *Occurrence and Production*

The chief minerals supplying commercial sources of lithium are spodumene,  $\text{LiAlSi}_2\text{O}_6$ ; amblygonite,  $\text{Li}(\text{AlF})\text{PO}_4$ , and the lithia mica, lepidolite. It is not uncommon to find these three minerals together in granite pegmatites. Spodumene and amblygonite are the main sources of the raw material for the manufacture of lithium salts, whereas lepidolite ranks as the most important lithium mineral for making certain types of glass.

Most of the world's spodumene comes from South Dakota mines in the U.S.A. At the Etta tin mine (which, incidentally, is not a tin mine) enormously large crystals of spodumene occur, some being over 40 feet in length and weighing over 40 tons. Important deposits of spodumene and amblygonite are found also near Winnipeg in Mani-

toba, and lithium minerals are worked in pegmatite veins in many countries. In 1938 lithium was recovered as a by-product in the form of lithium phosphate from the brines of Searles Lake in California.

Reliable figures of world production of lithium are unobtainable. In 1939 the U.S.A. output was nearly 2,000 tons. The same year South-West Africa produced 1,232 tons of lithium minerals; Argentina about 170 tons of spodumene, and Portugal about 110 tons of lithium minerals. In previous years France and Germany have recorded productions of several hundred tons of lepidolite. It is estimated that world production of all lithium minerals is about 3,000 tons, the U.S.A. being in normal times the chief source.

In 1952, the U.S.A. produced 13,938 long tons of lithium minerals; South-West Africa, 8,751; Southern Rhodesia, 1,321 tons.

## MAGNESIUM

THIRTY years ago magnesium, the lightest in weight of all metals, had very few industrial applications, being used mainly in pyrotechnics, as a flashlight powder for producing brilliant white light for photography, and to a minor extent in deoxidizing and desulphurizing other metals and alloys, especially nickel, brass and bronze. Its utilization in light alloys such as duralumin was then relatively unimportant, but within recent years there has been a rapid increase in demand for the metal in the manufacture of light, strong magnesium alloys for the aircraft and automobile industries. Most of the metal is now consumed in making castings for aircraft engines such as crankcases, oil-pans, pistons, bearings, control levers and so forth; and to

some extent as castings for optical instruments such as microscopes, for parts of cinema apparatus, artificial limbs, golf-club heads and other articles. Sheet and plate and tubing of magnesium are employed in the construction of aeroplane fuselages, cabins and steering parts; and the metal is utilized in a multitude of ways in which lightness combined with strength are of importance, as in textile machinery, electric fans and musical instruments. Its chief alloy is with aluminium, although magnesium-beryllium alloys are stated to be gaining favour on account of their great strength and lightness, this alloy being one of the lightest manufactured.

Metallic magnesium is now used extensively in making incendiary bombs, the walls of their tubes used in 1939 containing 93% magnesium and 7% aluminium, which burn at temperatures well above  $1,000^{\circ}\text{C}$ . The strong affinity of the metal for oxygen is also the reason why magnesium ribbon and wire are utilized in the degasification of radio valves to remove any traces of undesirable gases.

### *Occurrence and Production*

Before the 1914-8 world war magnesium metal was produced commercially only in Germany, where it was obtained by the electrolysis of molten magnesium chloride, a mineral which occurs in enormous quantities in the famous salt deposits of Stassfurt, referred to on p. 164. Germany has continued to be the world's largest producer and consumer of the metal, and before the outbreak of the Second World War the German output was 57% of the world total, most of it being derived from magnesium salts such as carnallite, the chloride of magnesium and potassium, and from the Austrian magnesite deposits. Similarly, almost the whole of the U.S.A. production of metallic

magnesium is from magnesium chloride obtained from natural brine in deep saline wells or from sea-water. In 1940 the U.S.A. produced 5,000 tons of the metal, and there has been a marked increase during the last two years.

In European countries other than Germany, the principal raw material for the production of magnesium is the mineral magnesite,  $\text{MgCO}_3$ , and to a small extent the mineral dolomite,  $\text{CaCO}_3\text{MgCO}_3$ . Magnesium compounds are now being recovered on a large scale from sea-water by a secret process. Sea-water contains about 1 part of magnesium in 800 parts of water, and the recovery of the metal from such a tenuous source presented unique chemical engineering problems. The hydrated oxide of magnesia,

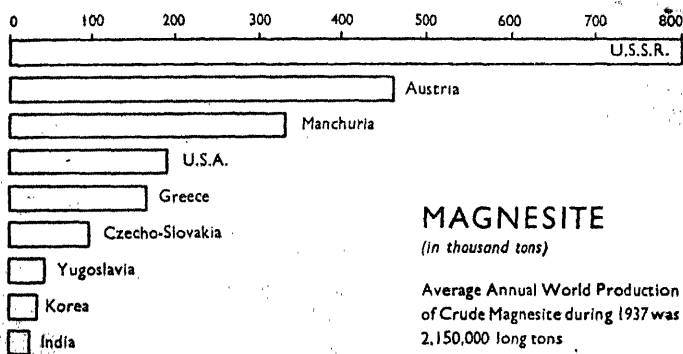


Fig. 13.

brucite, is also used as a source of magnesium in Canada and one or two other countries.

Magnesite has very important uses in addition to being a source of magnesium. It is mined on a large scale for making refractory bricks for lining basic open-hearth and electric furnaces and for use in basic converters. Dead-burned magnesite, prepared by prolonged heating of the mineral

at temperatures above  $1,500^{\circ}$  C. to expel all the carbon dioxide, is the chief product, and is the usual material employed wherever a basic lining capable of withstanding high temperature is required. Caustic calcined magnesite resulting from the heating of magnesite to  $1,000^{\circ}$  C., when it retains a small percentage of carbon dioxide, is employed in making strong, quick-setting cement such as magnesium oxychloride, formed by adding to the caustic magnesite a solution of magnesium chloride. The cement is plastic, becomes hard, tough and elastic, and is extensively used for flooring hospitals, offices, kitchens, ships' cabins and so forth, for it yields a non-slippery surface, is fireproof, warm under foot, flexible, can take a wax or oil polish and is easily cleaned. Caustic magnesite is also used in the manufacture of rubber. Crude magnesite is the source from which Epsom salts and other magnesium salts are prepared; and magnesium in one form or another has several other applications, as in ceramic insulators, extruded insulators for radio valves, opacifier in glazes, filler in paper-making, as a source of carbon dioxide, as a fertilizer; in sugar refining; and as a polishing medium and so forth.

Magnesite occurs in nature in two commercially important forms, the one compact or 'amorphous' and the other crystalline or spathic. The so-called 'amorphous' magnesite is usually found in veins ramifying serpentine, an altered basic igneous rock, or as a stockwork in the rock. It has been formed in most cases as the result of infiltrated carbonated waters which have reacted with the magnesia-rich serpentine. Deposits of this type generally yield high-grade magnesite, as in the famous Grecian deposits, notably those on the island of Euboea.

Crystalline magnesite deposits have in general originated as the result of the replacement of dolomite or of limestone by ascending magnesia-bearing solutions emanating from

an igneous magma, but in many cases much of the magnesia has been concentrated from the dolomite itself. Deposits of this type are usually lenticular or irregular in shape, and may conform to the stratification of the original bedded rock. Some such deposits are of enormous extent, with ore reserves exceeding a hundred million tons. Among the largest and most productive of this type are those of Satka in the Ural Mountains of the U.S.S.R.; in Manchuria; at Veitsch in Austria; in Slovakia; at Chewelah in the State of Washington; and in Quebec. Some few small deposits of magnesite, it has been suggested, may be of sedimentary origin, the magnesium content having been derived from saline residues.

Dolomite is far more abundant in nature than magnesite, and the mineral is used extensively for refractory purposes in basic open-hearth furnaces and basic converters, when it has been calcined to the dead-burned forms. It is not, however, as satisfactory for refractory purposes as magnesite, on account of its liability to disintegrate, but has the advantage of being relatively cheaper. More than half a million tons of dead-burned dolomite are consumed annually in the U.S.A., and over 600,000 tons annually in the United Kingdom.

Several processes with varying degrees of success have been devised for the extraction of magnesium metal from dolomite, and from dolomite mixed with magnesite. An important use of dolomite is in making basic magnesium carbonate, known also as 'technical carbonate' and 'magnesia alba', for employment when mixed with asbestos as heat-insulating coverings for steam pipes and boilers. A special kind of dolomite is used with magnesia for making 'Vienna lime' for buffing metals, particularly nickel, to produce the deep 'under-surface blue colour common to highly polished nickel articles'. Dolomite is used as a flux



in the metallurgical industry and as a building stone.

Beds of dolomite and of dolomitic limestone are of frequent occurrence in many countries. The Dolomite Alps of the Tyrol, for example, cover hundreds of square miles, and in this country in Nottinghamshire, Derbyshire, Yorkshire and Durham beds of it are common in the magnesian limestone series of the Permian System. Some dolomite beds have been formed by direct deposition from sea-water, but most deposits have resulted from the interaction of magnesium salts in sea-water which have converted the calcium carbonate into calcium magnesium carbonate. Most industrial countries have abundant domestic supplies of dolomite.

Brucite,  $\text{MgO} \cdot \text{H}_2\text{O}$ , is a mineral that is now being used in Canada and elsewhere for the production of metallic magnesium and magnesia. It has the advantage that it can easily be calcined into the oxide and subsequently converted into the metal, or for refractory or ceramic purposes. Large deposits of the mineral occur within the metamorphosed pre-Cambrian limestones of Ontario and Quebec; and large deposits of brucite, formed by the alteration of dolomite by igneous action, have been located in Nevada in the U.S.A.

The world production of magnesium metal in 1937 was just under 20,000 tons, and it is estimated that in 1940 this was doubled. Germany produced almost half of the total; the United Kingdom and the U.S.A. about a sixth, and Japan approximately one-tenth of the world production. France, the U.S.S.R., Switzerland and Italy in that order of importance are also producers of the metal.

World production of crude magnesite in 1937 was 2,150,000 long tons, of which the U.S.S.R. yielded 37%, Austria 21%, Manchuria 15%, the U.S.A. 8%, Greece 7%, Czechoslovakia 4%, Yugoslavia 2%, Korea 2% and India 2%. During the five years ended in 1952, the average annual

production of magnesite in the chief producing countries was: Austria, 566,076 long tons; U.S.A., 423,600; Czechoslovakia, 170,000; India, 79,931; Yugoslavia, 64,223; Greece, 39,125.

For this quinquennial period, the average annual world production of magnesite ore was 2,928,000 long tons.

## MANGANESE

MANGANESE is one of the key metals, its chief use being as a deoxidizer and desulphurizer in the manufacture of steel. Curiously enough, most of the manganese so used does not enter into the composition of the steel, but it has a cleansing effect during the smelting process. An analogy may be helpful to understand this: soap is used for washing clothes, but when the operation is completed little soap remains in the garments.

About 95% of world production of manganese is used for metallurgical purposes, and the remainder is consumed in a wide range of chemical uses, especially in dry batteries.

During the process of steel-making, ferro-manganese, which is an alloy averaging about 80% manganese, the rest being iron and carbon, is added to the furnace charge to prevent the formation of deleterious oxide and sulphide of iron in the finished steel. Since, however, a very small amount of manganese in steel increases its elastic limit and tenacity, enough is added to the melt to ensure the incorporation in the steel ingots of a fraction of 1% of manganese. Spiegeleisen, a ferro-alloy with approximately 20% manganese made from low-grade ore, is sometimes used instead of ferro-manganese. In many industrial countries about 54 lb. of manganese are consumed per ton of steel, but in U.S.A. during the last quarter of a century the

average has been just over 14 lb. per ton of steel.

Steels containing about 1% manganese are commonly used in structural work and for rails. For rock-crushers, sprockets, clutches, special lay-outs such as points and crossings, and in certain mining equipment requiring high tensile strength and resistance to abrasion, high-manganese steel with about 12% manganese is employed. A further but minor use is in non-ferrous alloys in combination with copper or aluminium in manganese bronzes, etc.

Quite important, though relatively small, is the amount of manganese consumed in non-metallurgical operations, such as in the chemical industry, where only high-grade ore is suitable. In dry cells the dioxide acts as a depolarizer; in varnishes, paints and inks manganese compounds are used as a drier; Condyl's fluid (a solution of sodium perman-

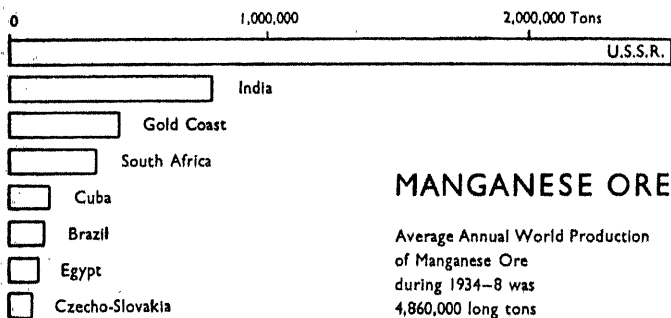


Fig. 14.

ganate) and potassium permanganate are disinfectants, and there are various other chemical uses.

### *Occurrence and Production*

Manganese does not occur in nature in metallic form. Most of it is obtained from the two black minerals, pyrolu-

site,  $\text{MnO}_2$ , and psilomelane, an impure hydrated oxide. These may be accompanied by other black oxides, such as wad or 'bog manganese', braunite and manganite. The carbonate, rhodochrosite (dialogite),  $\text{MnCO}_3$ , and the silicate, rhodonite,  $\text{MnSiO}_3$ , are pinkish in colour, and except where they have been oxidized to one of the black minerals they are usually not of commercial interest.

The most important manganese ore-bodies are of residual or of sedimentary origin resulting from concentration by natural agencies of the decomposition products of primary manganese minerals (especially manganese silicates like the manganiferous garnet, spessartite) which are sparsely distributed in many igneous and metamorphic rocks. By the weathering of such rocks the resulting manganese oxides are segregated as nodules and layers in the residual clay formed at or near the surface. Deposits of this origin are worked in India, Brazil, and the Gold Coast. In the sedimentary deposits the manganese has been precipitated from solution on to the floors of seas and lakes in the form of beds, of lenticular bodies, or as scattered concretionary masses, the precipitation commonly resulting from the action of algae and bacteria. When these deposits are raised above water level by crustal movements they frequently become considerably enriched by mechanical concentration, or by solution and re-disposition, of the manganese minerals. Such is the origin of the famous U.S.S.R. deposits at Nikopol in the Ukraine and Chiaturi in the Caucasus.

All gradations are known of manganese ores practically free from iron, and iron ores almost free from manganese. The term 'manganese ore' is restricted by some authorities to deposits containing not less than 35% of the metal.

The world production of manganese normally fluctuates in conformity with the output of steel, but in recent years

production has been well above consumption level owing to the accumulation of emergency stocks of this strategic mineral in many countries. It is an odd fact that some of the largest manganese ore-bodies are in countries that have no domestic use for manganese, whereas the two leading consumers, the U.S.A. and Germany, have a combined output of less than 1 % of the world total.

Since 1929 the U.S.S.R. has been the greatest producer of manganese, and is followed for second place by India, formerly the leading producer. In 1937 South Africa made a spectacular leap into third place, closely followed by the Gold Coast. A record world total of 6,000,000 long tons of manganese ore was reached in 1937, more than treble that of 1920. The geographical distribution of the chief manganese fields is shown in Fig. 30.

During World War II the Gold Coast became the largest supplier of metallurgical manganese ore to the U.S.A., Canada and Great Britain, almost all the ore being produced at Nauta, 40 miles by rail from Takoradi.

During the five years ended in 1952, the average annual production of manganese ore of the chief producing countries was: U.S.S.R., 2,960,000 long tons; India, 961,854; Gold Coast, 736,536; Union of South Africa, 660,600; French Morocco, 301,985; Brazil, 185,400.

For this quinquennial period, the average annual world production of manganese ore was 6,800,000 long tons.

## MERCURY

MERCURY, known also by its ancient name of quicksilver, is the only metal that is liquid at ordinary temperatures. Our predecessors used it for 'gilding', for making mirrors, and for collecting gold from auriferous gravels. Half a

century ago those were its most important uses, but are so no longer. It is still of great importance for the extraction of gold (and of silver), not, however, from alluvial deposits, but from the crushed rock or ore containing these precious metals which, when brought into contact with mercury, form pasty amalgams. The amalgam is heated in retorts, where the mercury is driven off as vapour and recovered, leaving behind the gold and silver as an almost pure spongy mass. Although this amalgamation method has been largely superseded by the more modern cyanide process of gold recovery, it is interesting to note that recently, particularly in the U.S.A., amalgamation is once more gaining favour.

Mercury is the only important metal whose consumption has not increased very markedly in the last sixty years, for, although numerous new uses have been found for it, substitutes have replaced some of its chief earlier applications. To-day only about a third of the world's total production is employed in the metallic state, the remaining two-thirds being used in the form of mercury compounds.

As metal, the principal uses are in the electrical industry for mercury-arc rectifiers, automatic switches for refrigerators, oil-burners and other types of apparatus. The columns of mercury in thermometers and barometers are familiar to everyone. Mercury is now used in a new type of mercury-vapour boiler instead of steam as the working substance. For initial filling of the boiler it requires over 100 tons of the metal, but so far this type of power generation is in operation in only a few large installations.

Mercury compounds have dozens of uses, such as in the manufacture of drugs and chemicals like corrosive sublimate (mercuric chloride), calomel (mercurous chloride), and in other pharmaceutical and dental preparations. In normal times, and more so at present, an industrial appli-

cation of prime importance is as fulminate of mercury, the most effective detonating agent for firing explosive charges in ammunition and blasting caps or detonators. An interesting application is that of the red oxide of mercury in paint applied to ships' bottoms to prevent fouling by barnacles, to which it becomes poisonous after chloridization by seawater. The sulphide of mercury, vermilion, has been used by the Chinese for over 1,000 years, and is still considered to be the best red pigment. Mercuric nitrate has long been used in the roughening and preparation of hair for felt hats, but substitutes are now being utilized.

### *Occurrence and Production*

Although a little mercury is found in nature as small globules in certain rocks, almost all of the metal is obtained from cinnabar, a red sulphide of mercury which may contain up to 86% of the metal. This mineral is found in rocks of all ages and of very different types, such as sandstones, shales, limestones, crystalline schists and igneous rocks, but in all cases there is evidence that the cinnabar was deposited from hot aqueous solutions during periods of volcanic activity. Most of the deposits of economic importance were formed comparatively near the surface during Tertiary times, and it is only in few cases that they persist to a depth of more than 1,000 feet, and rarely to 1,500 feet. Many hot springs in volcanic regions are at the present time depositing cinnabar. The mineral in workable quantities is generally confined to zones of fracture or broken ground, sometimes forming definite veins or lodes, and elsewhere it occurs scattered through the rocks as disseminations and impregnations.

The most productive and one of the deepest quicksilver mines in the world is that at Almaden in the Province of Ciudad Real, in southern Spain, where cinnabar, occa-

sionally containing small globules of mercury, is worked to a depth of 1,300 feet in Silurian quartzites. The upper parts of the mine were particularly rich, but in recent years the run-of-mine ore carries only about 6% of mercury, or less than one-third of its former tenor. The mine is under government control.

The Italian deposits are chiefly impregnations in shales and limestones, and average somewhat under 1% of mercury, the chief mines being at Monte Amiati in Tuscany and at Idria near Trieste.

Most of the United States production is from California, the chief mine being New Almaden, where particularly rich deposits, which in 1850 yielded ore with 37% of mercury, have become impoverished in depth, and at present yield only 0.4%.

The output of mercury in the U.S.S.R. is mainly from Nikitovka in the Donetz coal-basin of the Ukraine; that of Mexico chiefly from small mines in the States of Guerrero and San Luis Potosi. Since the outbreak of war in 1939

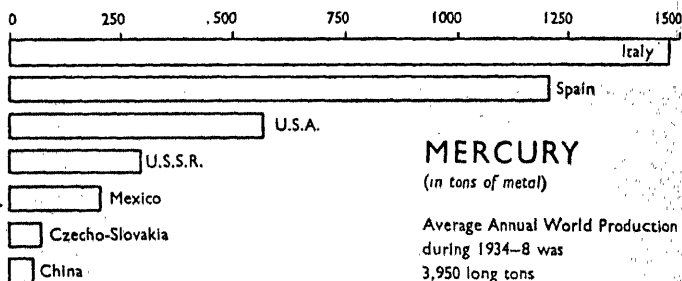


Fig. 15.

cinnabar mining has been revived in British Columbia, and an annual output of 300 or more tons of the metal was anticipated. Santa Barbara mine in Peru, once one of the most productive in the world, which yielded a total of



50,000 tons of mercury, was closed down 100 years ago. A similar though not so spectacular history applies to many derelict quicksilver mines. The geographical distribution of the chief mercury fields is shown in Fig. 28.

During the five years ended in 1952, the average annual production of mercury in the chief producing countries was: Italy, 1,668 long tons; Spain, 1,292; Yugoslavia, 457; U.S.A., 330; Mexico, 209; Japan, 71.

For this quinquennial period, the average annual world production was 4,400 tons of the metal.

Mercury is sold in strong wrought-iron flasks which can be handled and shipped without crating. The standard flask contains about 76 lb. of mercury and is the market unit of quantity. In May, 1941, the official price in London was established at about £48 per flask. During 1953-4 the price varied between £70 and £84 a standard flask.

## MICA

THE glistening substance on Christmas trees ('Jack Frost') and Christmas cards, on certain decorated wall-papers and in the sand of many beaches is the mineral, mica, for which, however, there are many more important uses than mere decoration. There are several varieties of mica, but the three chief are the white mica, muscovite, a hydrated silicate of aluminium and potassium; the amber mica, phlogopite, which is a magnesium-bearing mica; and the black or brown ferro-magnesian variety known as biotite. Of the three, muscovite is far and away the most important commercially; phlogopite has some very important uses, and biotite is utilized to a considerably lesser extent.

The value of mica for its chief industrial applications is on account of its perfect cleavage, which enables it to be separated easily into thin sheets, frequently, in the case of muscovite and phlogopite, to sheets less than a thousandth of an inch in thickness; to its flexibility, elasticity, low thermal conductivity, infusibility, transparency, lustrous cleavage faces; and, in particular for electrical purposes, to its high dielectric strength. No other mineral has better cleavage, flexibility or elasticity; it is possible to roll a sheet of muscovite a thousandth of an inch in thickness into a cylinder a quarter of an inch in diameter, and its elasticity would enable the sheet to flatten out again quite easily. Its high resistance to the passage of electricity is so great that no substitute, artificial or natural, has proved equally satisfactory, so that in the electrical industry it is as important as copper, and now ranks as one of the essential minerals in modern life.

Mica is employed in industry either as sheet or as ground or powdered mica. It has been estimated that 90% of the production of sheet mica is used in the electrical industry in condensers, telephones, dynamos, commutators and in making industrial or domestic heating equipment in which the wires or heating elements are coiled round the mica, which remains unaffected by the heat.

For most electrical purposes, especially for condensers and as insulating material between the segments of commutators of generators and dynamos, only the highest-quality mica is used; and the increased demand in recent years for use in radio, and in automobile and aeroplane engines, has been spectacular.

Phlogopite is more suitable than muscovite for separating the segments of a commutator, because it wears more evenly and at about the same rate as the metal bars; and the best grades of phlogopite, such as those produced in

Canada, are now used extensively in aeroplane sparking-plugs.

A considerable amount of muscovite is used for condensers and other electrical purposes in the form of superimposed thin splittings cemented together with shellac or special synthetic resins, heat-pressed into plates and blocks of required thickness, and shaped as desired. The product is known in the trade as 'Micanite'. Muscovite can be used only where the temperatures will not exceed  $550^{\circ}\text{C}$ ., whereas phlogopite can withstand temperatures up to  $1,000^{\circ}\text{C}$ . Chimneys for lamps burning oil or gas, windows or peep-holes in ovens, furnaces and stoves, and in optical lanterns are some of the other uses of muscovite.

Mica which is unsuitable for use as sheets, and the part of sheets trimmed off, is marketed as scrap or ground mica. About two-thirds of all such mica is utilized in the roofing trade as a backing for rolled asphalt roofing and shingles to prevent sticking, and to a lesser extent as a decorative surface for these materials. Some scrap mica is mixed with shellac and moulded for use in electrical insulation. Approximately 10% of ground mica is employed to give lustre to decorated wall-paper; 7% is used in paints, and 6% as a filler in rubber and as a dusting medium to prevent rubber tyres and rubber goods from adhering to the moulds in which they are shaped. Among miscellaneous uses for ground mica are: to give a finish to stucco and concrete; in the making of artificial stone slabs and blocks; for lubrication in axle grease and as a dry lubricant.

Biotite is rarely used in sheet form, as it is frequently spotted with impurities such as iron-bearing minerals. It is used almost always in the powdered form as a coating or filler material in the roofing, rubber, building or other trades.

### *Occurrence and Production*

Single crystals of muscovite may attain a diameter of 12 feet, and on one occasion in North Carolina in the U.S.A. a single crystal weighing almost 2 tons was found! Usually, however, in commercial deposits the crystals vary from a few inches to a foot or so in diameter and from a fraction of an inch to 1 or 2 inches in thickness. They are referred to as 'books' of mica, a good descriptive name, for, although the crystals are often somewhat hexagonal, they can be split into sheets almost as easily as the pages of a book are separated.

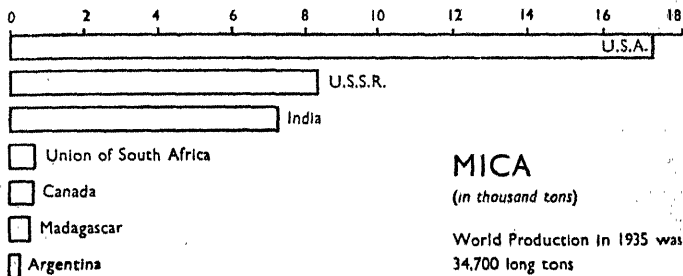


Fig. 16.

Muscovite in economic quantities is confined to coarse-grained granite pegmatite dykes consisting largely of quartz, felspar and mica. The dykes are of acid igneous origin, and the minerals were probably formed direct from the magma. The world's chief deposits of muscovite are in India at Bihar and in the Nellore district of Madras. Together, these have supplied over 70% of the world total of *sheet* mica during the past thirty years. The pegmatite dykes traverse gneissoid rocks, and the muscovite crystals normally do not exceed a foot in diameter, although much larger crystals are occasionally found. Large quantities of

muscovite are produced also from pegmatites in New Hampshire and North Carolina in the U.S.A., but only a small percentage is of sheet-quality, the rest being used as ground mica. Brazil is becoming an increasingly important producer of high-grade muscovite.

Phlogopite, on the contrary, is associated with basic igneous rocks, especially pyroxenites, which are intruded into metamorphosed limestones and gneisses. For many years the Canadian deposits in Ontario and Quebec, within 100 miles of Ottawa, were the only important sources of phlogopite, but during the thirties Madagascar became a prominent producer of the mineral. The higher cost of phlogopite prevents it from competing successfully against muscovite except for electrical insulation, for which purpose it is preferable, whereas for condensers it is unsuitable. South Africa produces muscovite from pegmatites in N.E. Transvaal, and the U.S.S.R. both muscovite and phlogopite from various areas, notably phlogopite from the region near Lake Baikal in Central Siberia and muscovite from Karelia and Siberia. The name muscovite is derived from Muscovy (Russia), where the mineral was in early use as window-glass.

Mica deposits are notoriously unsatisfactory for mining purposes, owing to the very sporadic manner in which the crystals occur; and phlogopite is even more sporadic in occurrence than muscovite. There are few helpful indications to guide the miner, hence the saying that 'mica is where you find it!'

The latest fairly *complete* figures of world production of mica of all grades are those of 1935, when nearly 35,000 long tons were produced. Of this tonnage, the U.S.A. yielded 50%, the U.S.S.R. 23%, India 20%, Union of South Africa, Canada, and Madagascar each approximately 2%. It is estimated that in 1937 the production

reached about 50,000 tons. Fig. 16 refers to total mica, sheet and scrap or ground mica. India yielded in 1937 nearly 90% of the world sheet mica; the U.S.A. just under 10%, and Madagascar came third. Canada's production of 3,677 metric tons of phlogopite in 1929 had decreased in 1937 to only 816 tons.

During the five years ended in 1952, the average annual production of the chief producing countries was: India (exports), 17,596 long tons; Canada (sales), 1,987; Union of South Africa, 1,623; Brazil, 1,512; Madagascar, 845; Norway, 500; Southern Rhodesia, 415.

For this quinquennial period, the average annual world production of mica was 78,380 long tons.

The geographical distribution of the chief mica fields is shown in Fig. 29.

## MOLYBDENUM

FIFTY years ago almost the whole of the world production of molybdenum was consumed in making chemical reagents, chiefly ammonium molybdate for the analytical determination of phosphorus in fertilizers, iron and steel and other products. To-day its principal use is in the manufacture of special steels. The addition of 1% or less of molybdenum to steel, either alone or in combination with other steel-alloying elements, enhances the elastic limit, tensile strength and ductility of the steel. Early attempts proved unsuccessful, and it was not until 1917 that molybdenum-bearing steels became important products. Their increasing utilization is shown by the fact that the total world production of molybdenum in 1940 was 16,000 long tons, or ten times that of 1930.

Large quantities of molybdenum are now consumed in

the manufacture of high-speed tools, self-tempering tools which can cut ordinary steel much as a knife cuts cheese; and in die steels. Molybdenum-bearing steels are finding increasing uses in automobile parts, machine tools, excavating machinery, pumping equipment, aircraft, locomotive reciprocating parts, agricultural implements, oil refineries, drilling rigs and for many other purposes. Steels containing a relatively high percentage of molybdenum are used for permanent magnets and rustless steels. Molybdenized chromium steels are employed in structural work, in mining equipment where resistance to abrasion is required, and in strong, thin-walled, seamless tubing. During recent years molybdenum cast irons have gained favour for service where resistance to pressure and machinability are of importance. Non-ferrous stellite alloys are composed mainly of cobalt, chromium and molybdenum, and possess some of the qualities of high-speed cutting steels. Molybdenum in metallic form is employed for a variety of electrical purposes, such as a support for lamp filaments, for windings of electric resistance furnaces, X-ray tubes and wireless apparatus.

Various compounds of molybdenum are employed as chemical reagents, catalysts, pigments for leather, rubber and woollens, etc., and in enamels and 'finishes' for metallic parts.

### *Occurrence and Production*

Molybdenum in the metallic state does not occur in nature. It is all obtained from two minerals, mainly from molybdenite,  $\text{MoS}_2$ , and a lesser amount from wulfenite,  $\text{PbMoO}_4$ .

Molybdenite is a soft, lead-grey mineral and, like graphite, which it resembles in appearance, will mark paper. It is usually found in association with granite and

granitic rocks, particularly granite pegmatites and related quartz veins. Occasionally workable deposits have resulted by the replacement of limestones by mineralizing solutions that have emanated from nearby granitic rocks, which themselves often contain the mineral as segregations and disseminations. In pegmatites and veins of deep-seated origin the mineral may occur in relatively large patches, whereas in deposits formed at high levels it is usually present as small or even microscopic scales.

Wulfenite, a yellow to orange mineral usually in tabular form, is of secondary origin, and not uncommon in the near-surface oxidized parts of deposits where the primary ores contain molybdenite and galena.

During the quinquennial period 1934-8 the average annual world production of molybdenum was nearly 10,000 long tons, about 90% of which was from the United States, 5% from Mexico, and 3-4% from Norway. Climax, in Colorado, U.S.A., was the chief centre of production and the Climax Molybdenum Company had a virtual monopoly of the molybdenum market for twenty-three consecutive years until 1947 when the Utah Copper Division of the Kennecott Copper Corporation became the main producers of the metal, which is obtained as a by-product from its copper concentrates.

During the five years ended in 1952, the average annual production of the chief producing countries was: U.S.A., 475,684 cwt. in terms of  $\text{MoS}_2$ ; Chile, 35,600; and Norway, 3,090 cwt. For this quinquennial period, the average annual world production was 513,340 cwt., in terms of  $\text{MoS}_2$ .



## MONAZITE

THE metal that yields the spark in the familiar pocket-lighter is cerium alloyed with iron, and the chief source of cerium is the mineral, monazite, essentially a phosphate of cerium, but usually containing a small percentage, from traces up to 18%, of thorium. Monazite is also the principal source of the lanthanum and neodymium, praseodymium and other 'rare-earth' metals, and of the radioactive element, mesothorium; besides providing most of the world's thorium requirements. Its composition is usually expressed as  $(\text{Ce, La, Nd, Pr})\text{PO}_4$ , but as found in nature it almost always contains varying amounts of thorium and certain other impurities.

The once-popular incandescent-gas mantles provided the most important use of monazite as the source of thorium for the thorium nitrate employed in their manufacture; and even in the electric lamps which supplanted the gas mantles, metallic thorium is sometimes alloyed with tungsten for making more ductile the lamp filaments. The mesothorium which invariably accompanies the thorium is utilized as a substitute for radium, and, although 1 ton of monazite containing 5% of thorium yields only 2.5 milligrams of mesothorium, the high price of this element warrants the expense of its recovery.

Cerium and its salts have many applications. When alloyed with iron in the ratio of 70% cerium and 30% iron, it forms a pyrophoric alloy now extensively used for the pocket-lighter and for lighting inflammable gases in carbide lamps. This alloy is frequently erroneously referred to as 'sparking flint', whereas its only connexion with flint is its use for yielding sparks.

Large quantities of cerium are utilized in making electrodes for electric-arc lamps, and for searchlights when mixed with thoria. Cerium salts find a limited use in medicine, ceramics, tanning, dyeing and in the manufacture of optical glass.

### *Occurrence and Production*

Monazite, as its name implies (Greek for 'to be solitary'), is very restricted in its occurrence, and the bulk of the world's supply comes from the beach-sands of Travancore, in south-west India, where natural agencies have concentrated the monazite and the accompanying zircon and ilmenite. It occurs as a primary mineral in granites and gneisses, and large crystals, weighing in exceptional cases up to 30 lb., have been found in granite pegmatite dykes. But in no recorded case has sufficient monazite been found to pay for crushing and recovering monazite from the original rock. The mineral, however, is so resistant to decomposition that its honey-yellow grains liberated during the weathering of the granitic rocks remain unaltered and, by virtue of its higher specific gravity than the quartz and felspar in the rocks, the rounded grains of monazite become concentrated with other heavy minerals in stream-beds and by tidal and wave action along sea beaches, to form workable alluvial deposits.

The famous monazite deposits of Travancore are beach sands along the extreme south-west of India, where, in certain localities, half the crude sand may consist of monazite, though usually the amount averages about 5%. It is fortunate that the mineral is slightly magnetic, and is thus amenable for recovery by electromagnetic separation, the final product containing 90% of monazite. Similar deposits were formerly worked on a small scale along the neighbouring coasts of Ceylon.

Until 1911 Brazil was by far the largest producer, with an annual average output of 3,000-4,000 tons, obtained from coastal sands near Prado in the State of Bahia and from various other beaches. The better quality and lower price of Indian monazite caused a rapid decline in the Brazilian production, which in 1938 was only 318 tons. Moderate tonnages of monazite in the past few years came from the Netherlands East Indies, and intermittent small supplies from various states in the U.S.A. The mineral is known to occur also in eastern parts of Australia, in the tinfields of Nigeria and Malaya, in Nyasaland and in Norway, all of which may in future become sources of monazite.

In 1938 the world production of monazite was 5,926 long tons, of which India supplied 88%, Netherlands East Indies 6.5%, and Brazil 5.5%.

Since the end of World War II, except for strategic considerations, the ordinary export of monazite from India has been stopped. India possesses the largest reserves in the world of this mineral, occurring in readily accessible form of beach sands. In 1941, India exported 3,475 tons of monazite; in 1945, less than half that tonnage; and in 1946, only 60 tons. Reliable production figures about this highly strategic mineral are not available. It is known, however, that Brazil produces about 2,000 long tons a year and that for the five years ended in 1952, Australia produced annually an average of 180 tons of low-grade monazite concentrates.

## NICKEL

THE importance of the little salt used in cooking a meal is out of all proportion to the amount used, and similarly the total consumption of nickel employed in industry is but a

very slight indication of the tremendous importance of this metal in its exceptionally wide range of applications that are still increasing rapidly as, for example, in the superalloy field for high temperature use in jet engines.

About 60% of the world's present production of about 110,000 long tons is used in steels, either alone or in company with chromium, manganese and other metals. It was only after long and painstaking researches that metallurgists were able to use nickel to the best advantage in steels, because surprisingly different results are produced with small variations in the percentages employed. It was found that with an addition of less than 2% of nickel in steel, little advantage was gained, whereas 'with between 2% and 4% the tensile strength of steel was increased about 6,000 lb. per square inch for each per cent of nickel added, and that the product was more resistant to rusting and abrasion. With more than 10% nickel the steel, instead of getting harder when heated and chilled, gets softer. Steel containing 13% nickel is tremendously strong, but so hard that it can hardly be cut or drilled. . . . At 24% nickel the alloy becomes non-magnetic, and with from 24% to 32% it has a high resistance to the passage of electrical current'. The latter alloy is thus employed for the heating coils in electric radiators, toasters and so forth.

Low nickel steels with less than 7% nickel are of such high strength, ductility and toughness that they are much used in automobile and aircraft construction, railway and power equipment, mining and mill machinery and for machine tools. High nickel steels, with 7%-35% nickel, usually with some chromium, include the heat-resistant and corrosion-resistant stainless steels, widely used in chemical apparatus, domestic and marine fittings, turbine blades, and in the food industry.

The addition of a small amount of nickel increases the

strength, hardness, corrosion resistance, castability and machining properties of cast iron. These nickel cast irons are employed in automobile and Diesel engines, rolling and refinery equipment, valves, pumps, air compressors, chemical apparatus and for a variety of other purposes. Ferro-nickel alloys have a wide range of magnetic, electrical, and thermal properties, depending on the percentage of nickel used; and non-magnetic alloys with from 10% to 25% nickel are utilized in parts of transformers, motors and generators. Highly magnetic alloys, with 45-80% nickel, find use in submarine cable sheathing, radio transformers, and telephone and telegraph relay parts; and low expansion alloys with 35-45% nickel, for precision instruments, measuring tapes, thermostatic controls, etc. Nickel steel, with 36% nickel, has the very remarkable property of not expanding or contracting appreciably with ordinary changes of temperature. It is called 'invar', being invariable at all air heats, and thus useful for measuring tapes and standards of length.

Alloys of nickel with copper combine strength with resistance to corrosion and find service as condenser tubes, marine equipment, electrical resistance wire, coinage and numerous other minor applications. When zinc accompanies the nickel and copper, a range of alloys is produced for decorative purposes and as a basis in silver-plated ware. Among non-ferrous nickel alloys, nickel bronzes are utilized in marine and general engineering; and a small amount of nickel in aluminium alloys endows them with an added high-temperature strength, valuable for service in aeroplane and other internal-combustion engines.

Monel metal, 67% nickel and 28% copper, is a special type of alloy of high tensile strength which has very wide applications. Pure nickel is used principally in electroplating, either as the complete coating or as an undercoat

to a chromium finish; it is also employed in the chemical, electrical, dairy food and petroleum industries. Finely powdered nickel is used as a catalyst in a number of chemical reactions, especially in the hydrogenation of oils to form solid fats. Nickel and its salts are used for alkaline storage batteries, enamels and as chemical reagents.

The utilization of nickel in steels for armour plate, gun forgings, bullet jackets and many items of naval construction is, of course, of great importance.

It is estimated that in 1939 the percentage consumption of nickel for its main uses was as follows: steels (including constructional, stainless, corrosion- and heat-resisting), 60%; nickel-copper and nickel-silver, 10%; Monel, malleable nickel, 10%; electrodeposition, 8%; nickel cast iron, 3%; heat-resisting and electrical resistance alloys, 3%; nickel brass, bronze and aluminium alloy castings, 2%; other uses, 4%.

### *Occurrence and Production*

More than 86% of the total nickel production of the world is in the Sudbury district of Ontario, Canada, from nickel-copper-iron sulphide ores, which also yield, as a by-product, the greatest supply of platinum and platinum metals (see p. 151). All the mines at Sudbury, except Falconbridge, are owned by the International Nickel Company of Canada.

The nickel in these ores is present as pentlandite,  $(\text{FeNi})\text{S}$ , in intimate association with pyrrhotite,  $\text{Fe}_n\text{S}_{n+1}$ , and chalcopyrite,  $\text{CuFeS}_2$ , the average ore containing about 3% nickel and 2% copper, the dominant mineral being pyrrhotite, in which most of the pentlandite occurs as scattered grains. In some of the mines, as at Frood mine - the largest - the nickel content decreases slightly in depth and there is an increase in the copper content, occasionally

up to 20%. In places the deposits have been proved to a depth of 4,000 feet, and the ore reserves are estimated to be over 200 million tons, so that Sudbury's nickel resources are assured for many years.

The ore-bodies at Sudbury are found at intervals along or near the base of a thick sheet of norite, a basic igneous rock frequently referred to as the 'nickel eruptive', which occupies a basin, elliptical in form, some 36 miles long and 16 miles wide. The origin of the Sudbury deposits is controversial, but all authorities agree that the ores are genetically related to the norite. The earlier theory of a gravitative settling of the sulphides in the magma and their consolidation at its base has proved on further evidence to be untenable, and the view now held by the geologists at Sudbury who have studied the area in great detail, is that dilute sulphide melts were injected along certain brecciated or fractured zones, frequently of diorite, after the norite had consolidated. In some places the ores may have been formed by direct replacement of the rocks by sulphidic melts or solutions introduced after the crystallization of the norite.

Nickeliferous sulphide deposits associated with basic igneous rocks, and similar in many respects to those of Sudbury, but not so extensive, occur also near Petsamo in Finland, and preparations were well advanced to work these ores before the outbreak of war between Finland and the U.S.S.R. in 1937. One of the results of that war was the acquisition by the U.S.S.R. of the Petsamo nickel deposits. Such sulphide bodies are known also in Norway and the U.S.S.R., but so far these two countries have not been important producers of the metal.

Until 1905 the French colony of New Caledonia, in the South Pacific, was the world's chief producer of nickel, but it now produces only about 6% of the total. The nickel

mineral at New Caledonia is garnierite, a hydrated nickeliferous magnesium silicate which occurs very sporadically in small discontinuous veins and in pockets in serpentine rocks which are weathered to variegated clays on the surface. The recent annual production of this French colony was about 6,000 tons of nickel, in terms of the metal.

During the 1914-18 world war the total annual production of nickel was some 40,000 tons; it dwindled to 10,000 tons in 1921; and reached its peak of more than 110,000 tons in 1937.

The nickel production of Sudbury in Canada reached its pre-war peace-time peak in 1937 with a yield of 132,000 tons, and its war-time peak in 1943 with 144,000 tons. Finland in 1943 produced 4,572 tons.

During the five years ended in 1952 the average annual production of the chief producing countries, in terms of the metal, was: Canada, 118,180 long tons; U.S.S.R., 25,000; New Caledonia, 7,260; Cuba, 6,000; Union of South Africa, 850; U.S.A., 710. For this quinquennial period, the average annual world production was 154,000 long tons.

The geographical distribution of the chief nickel fields is shown in Fig. 30.

## NITRATES

MOST nitrate minerals are very soluble in water, so that their occurrence is confined mainly to arid regions. Two only of these are of industrial importance, and they are nitratine,  $\text{NaNO}_3$ , frequently known as Chile saltpetre or soda nitre; and nitre,  $\text{KNO}_3$ , or saltpetre. Nitratine is by far the more important of the two, and this mineral yielded all the world's requirements of nitrogen for a period of fifty years following the initial exploitation in 1825 of the Chilean



deposits. By 1900, however, about one-third of all combined nitrogen was being recovered as a by-product in the coking of coal. Then followed development of the fixation processes for extracting nitrogen from the air, the first recorded production being in 1906. Shortly afterwards came the successful direct synthesis of ammonia from nitrogen and hydrogen, and this synthetic process now yields approximately three-fourths of the world's nitrogen output. At present combined nitrogen production is about 75% from the atmosphere, 17% from coal and only 8% from Chile saltpetre.

Of the world consumption of nitrogen compounds, about 80% is employed by the fertilizer industry, mainly in the form of ammonium sulphate, sodium nitrate and calcium cyanamide.

The Chilean nitrate deposits contain many impurities, such as potassium, magnesium, iodine and boron, which are valuable for the development of plant life; and, although not used so extensively as ammonium sulphate, Chile saltpetre is still important for agriculture.

Some of the chief uses of nitrogen compounds are in the form of explosives such as trinitrotoluene (TNT), nitroglycerine and nitrocellulose; in the manufacture of nitric acid, which consumes large quantities of nitrogen; and in many other compounds, notably ammonia and its numerous salts. Sodium nitrate is used in glass, dye and chemical works.

### *Occurrence and Production*

The only part of the world where nitrate deposits are worked on a large scale is in the Atacama desert regions of northern Chile, in the dry valleys between the Coast Range and the Andes at a height of some 2,000 feet above sea level. The deposits are scattered along a belt from 5 to 40 miles

wide, which stretches parallel to the coast for a distance of more than 300 miles, and is within a barren, desolate, rainless region.

The 'caliche' or nitrate bed is from a few inches up to 14 feet in thickness and lies on the surface beneath a shallow overburden. It contains from 14% to 25% of sodium nitrate with 2% or 3% of potassium nitrate, 8% to 50% of sodium chloride, and numerous sulphates, borates and iodates. All these soluble salts occur as cementing material in a reddish-brown sandy gravel, and it is stated that many hundred million tons of deposit are still available for exploitation.

The origin of the Chilean nitrate deposits is puzzling, and many theories have been advanced to explain it. Some authorities have maintained that the fixation of the nitrogen was the accumulated result of thunderstorms (it is known that lightning discharges produce oxides of nitrogen); others that the nitrate was derived by the leaching of bird guano; a few suggest bacterial fixation; and oxidation of nitrogenous vegetable matter has also been advanced as the explanation. It is significant that in their extent the caliche deposits correspond fairly closely to tuffs (volcanic rocks) of the Jurassic and Cretaceous. This fact, together with the presence of borates, suggests strongly that the sodium nitrate may have been derived from volcanic rocks by leaching under unusually arid conditions.

Since 1825 the Chilean deposits have yielded about 85 million tons of nitratine, and in 1938 the output of sodium nitrate was about 1,400,000 long tons, which is only half the production of the peak years 1928 and 1929. Before the development of synthetic nitrogen, no other mineral industry had such a monopoly as that of Chilean saltpetre.

During the five years ended in 1952, the average annual production of nitrate of soda in Chile was 1,630,000 long tons, and of nitrate of potash in India, 5,920 long tons.

## PHOSPHORUS

No animal or plant can exist without phosphorus, and of all the substances necessary for plant growth, compounds containing available phosphorus are the most liable to be deficient. This is not because phosphorus is scarce in nature, but because in the mineral world it is frequently in a form which plants cannot use. Animals eat plants, and thus obtain phosphorus to build bone, but before the calcium phosphate in animal bone can be assimilated by plants, the bone must be ground into a fine powder, and even then the plant roots extract it with difficulty. It is in making phosphorus more easily available to plants that the chemist has proved so helpful: he converts the insoluble natural phosphate into a soluble 'super-phosphate'.

The importance of phosphates in agriculture has been known for over a century, and in recent years it has been calculated that a ton of wheat extracts on the average from the soil about 47 lb. of nitrogen, 18 lb. of phosphoric acid and 12 lb. of potash; and, unless these losses are replaced, the fertility of the soil is decreased. Grain depletes the soil's supply of phosphorus more rapidly than most crops, for the element is largely transferred to the ripened seeds, which thus become valuable as food for man and animal.

The two principal varieties of natural phosphates are: (1) rock phosphates such as phosphorite, phosphatic limestones, guano, and bone beds, and (2) the mineral, apatite,  $3\text{Ca}_3\text{P}_2\text{O}_8\text{CaF}_2$ , which in a few cases contains chlorine instead of fluorine. Large amounts of phosphorus-containing fertilizer are obtained by grinding phosphorus-bearing slag recovered from basic steel furnaces ('basic slag', which supplies Germany with about half her consumption of phos-

phates); also from manure: a ton of farmyard manure contains about 5 lb. of phosphoric acid. A considerable amount of phosphorus is present in city sewage, which in future will probably not be permitted to run to waste.

Finely ground rock phosphate or apatite, otherwise untreated, may be spread directly on the land, but this raw material is not readily soluble in water or in the dilute acids formed by vegetable humus, but, nevertheless, decomposes slowly, thereby enriching the soil. Experiments carried out in this country a century ago at Rothamsted by John Lawes led to the initiation of the great superphosphate industry, and Lawes patented a soluble artificial manure made by treating mineral phosphates with sulphuric acid. It is now common practice to treat phosphate rock or apatite in this way, and it generally requires about equal weights of the raw material and of sulphuric acid for this conversion into soluble superphosphate, or, to be more strictly correct, into acid phosphate. About  $1\frac{1}{2}$  million tons of sulphuric acid are used annually in the U.S.A. for this purpose.

Ordinary superphosphate contains not more than 18% of phosphoric acid,  $P_2O_5$ , and is thus a low-grade product which will not stand high freight charges or long shipment. For this reason double superphosphate (also known as triple or concentrated superphosphate) containing from 45% to 50% of phosphoric acid in soluble form is now manufactured extensively by treating the raw material with phosphoric acid instead of with sulphuric acid. Important among other ways of producing water-soluble phosphate fertilizers is smelting the raw phosphate rock in an electric furnace to obtain phosphoric acid, and this pyrolytic method has the advantage of being able to treat low-grade natural phosphates without employing sulphuric acid, and of reducing the bulk of the finished product.

Small amounts of phosphate rock are used for various other industrial purposes, such as the production of metallic phosphorus, high-grade phosphate chemicals, phosphate

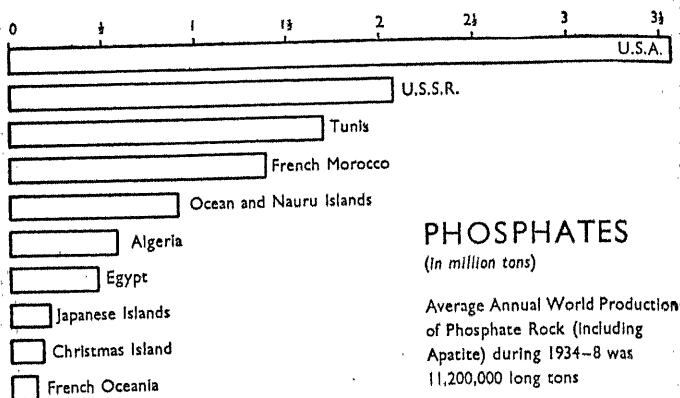


Fig. 17.

water-softeners, baking-powder, refractory bricks, and the preparation of stock foods. Considerable quantities of the raw material are also smelted in blast-furnaces for making ferrophosphorus; and phosphor bronze is a well-known and extensively used alloy.

### *Occurrence and Production*

The mineral apatite is the chief primary source of phosphorus. It occurs as a minor constituent in most types of igneous rocks and sparingly in many sedimentary and metamorphic rocks. In workable quantities, however, it is confined to a few parts of the earth's crust, such as the pegmatite veins traversing limestones in Ontario and Quebec; the veins and pockets associated with the gabbros of Norway; the famous magnetite deposits of Kiruna and Gellivare in Sweden; and the largest of all, in great lenses of

apatite-nepheline rock in northern U.S.S.R., discovered in 1926 and producing, by 1937, more than 2 million tons of apatite rock annually.

Rock phosphate often results from the leaching of guano, a deposit accumulated from the excrement of sea-birds which have congregated over long periods on oceanic islands and on desert coasts, as in Christmas Island in the Indian Ocean, on innumerable Pacific islands, and along the Peruvian and Chilean coasts. The guano may be over 100 feet in thickness, and the phosphoric acid leached from it infiltrates downwards, and if the underlying rock happens to be limestone, it is converted into phosphate rock.

Phosphate rock also occurs in beds of marine origin, usually interstratified with limestone, marls, sandstones or shales. These phosphate deposits probably derived their material from decaying organic matter accumulating on the sea-floor where the organic phosphate reacted with calcium carbonate, or lime, to form concretions or nodules of calcium phosphate. Mineralogically, the most important constituent of phosphate rock is collophane, or collophanite,  $\text{Ca}_3(\text{PO}_4)_2\text{H}_2\text{O}$ .

'The cycle of migration of the phosphates is a fascinating study. From their original home in the igneous rocks they are dissolved by surface waters and absorbed by all living things, vegetable and animal, on land and sea. After the death of the organisms the phosphates return to the soil or to the sedimentary beds to be dissolved and used over anew by other generations.'

Commercial rock phosphate deposits usually contain 60% to 90% of tricalcium phosphate; those of the U.S.A. and of Tunis have about 70%, whereas the Ocean Island deposits frequently average more than 85%.

The accompanying diagram, Fig. 17, is compiled for the quinquennial period 1934-8, during which the average

annual production was 11,200,000 long tons of phosphate rock, including apatite. This was distributed as follows: U.S.A., 31.5%; U.S.S.R., 18%; Tunisia, 14.9%; French Morocco, 11.9%; Ocean and Nauru Islands, 8.1%; Algeria, 5.1%; Egypt, 4.2%; Japan, 1.8%; Christmas Island, 1.4%; French Oceania, 1.1%; all others 2.0%. The geographical distribution of the chief phosphate fields is shown in Fig. 29.

Consumption of phosphate rock in the U.S.A. has increased from an average annual pre-war level of  $2\frac{1}{2}$  million tons to over 10 million tons under present high farm income.

During the five years ended in 1952, the average annual production of phosphates (phosphate rock, including apatite) in the chief producing countries was: U.S.A., 10,310,965 long tons; Morocco (French), 3,830,800; U.S.S.R., 2,560,000; Tunis, 1,727,100; Nauru Islands, 890,450; Algeria, 684,038; Egypt, 422,770.

For this quinquennial period, the average annual world production was 21,813,200 long tons.

## THE PLATINUM GROUP METALS

PLATINUM was first discovered by the Spaniards about 1735 in Colombia, South America, and because of its silvery colour was named 'platina', the Spanish for silver being 'plata'. At first there was no use for it, but in 1778 its recovery from the Colombian deposits, where it occurred with gold in gravels, was begun in earnest, and that was the only source of the metal until 1783, when rich platinum-bearing alluvial deposits were discovered in the Urals, Russia. For the next hundred years Russia provided most of the world's platinum requirements, supplying in 1913

almost 93% of the total production, Colombia providing the remaining 7%. Platinum concentrates were first produced in Canada in 1909 by the Mond Nickel Company from the Sudbury deposits, and the platinum was refined at Acton in England. Canada became an important producer in 1923, since when the recovery of platinum as a by-product from the nickel ores of Sudbury, Ontario has increased rapidly, and now exceeds that of the U.S.S.R.

Platinum is the commonest member of a group of metals which includes also palladium, osmium, iridium, ruthenium and rhodium. All six metals are usually found in intimate association, and except in rare instances platinum, as found in nature, is invariably alloyed with other metals of the platinum group and with gold and iron.

Osmium, iridium and platinum in that order are the three heaviest metals known, and, with the exception of palladium, the members of the group are characterized by their insolubility in ordinary acids. In addition, their high melting points, their resistance to heat, and to oxidation at ordinary temperatures, endow them with valuable properties utilized in the chemical, electrical, and metallurgical industries.

In times of peace the chief consumption of platinum was in jewellery, and between 1918 and 1940 more than half the platinum used in the U.S.A. was for that purpose. In 1939, the latest year for which complete figures are available, the consumption of the metal in the U.S.A. was: in jewellery, 36%; for dental purposes, 23%; electrical, 22%; chemical, 14%; and miscellaneous uses, 5%.

The metal is highly prized in many kinds of ornamental jewellery, especially as a setting for diamonds, the brilliancy of which is enhanced by the metallic white colour of the platinum. At one time (in 1918-20) it was more than £20 per ounce, or more than six times the then price of gold,



but the depression that later followed and the increase in production of the metal by the International Nickel Company of Canada at Sudbury brought down the price in 1931 to less than one-half of the 1928 average, and to almost a quarter of that of 1920. It is now a little higher than twice the price of gold, £27 as against £12·4 per troy ounce.

The chemical uses of platinum include laboratory apparatus such as crucibles, dishes, foil and wire; and the employment of platinum-clad industrial equipment is increasing. A large proportion of platinum is utilized for catalytic purposes in the manufacture of sulphuric acid by the so-called 'contact process'; in the synthesis of ammonia from hydrogen and nitrogen; and for the oxidation of ammonia to nitric acid. Platinum and palladium are also employed as catalysts in synthetic organic chemistry, particularly in the hydrogenation of many organic compounds. In the electrochemical industry, platinum is often used as electrodes - for example, in the manufacture of persulphate, etc.

Among the principal uses of the platinum metals in the electrical industry are as contact points, in telephone and telegraph apparatus, and magnet contacts. Platinum-iridium alloys are hard, tough and do not corrode, and are thus particularly suitable in electrical contacts used under severe conditions, such as occur in aircraft. There has been considerable increase in the last few years in the demand for palladium as a substitute for platinum in electrical work owing to its relative cheapness (a cubic inch of palladium weighs little more than half that volume of platinum), and since 1936 almost twice as much palladium as platinum has been utilized in the U.S.A. for that purpose. In 1939 the electrical industry in that country consumed 32,548 ounces of palladium as against 17,548 ounces of platinum.

In dentistry, platinum and an increasing amount of palladium are used as plates and supporting pins for artificial teeth and in dental alloy.

For the measurement of high temperatures platinum is employed in thermoelectric and resistance thermometers; and thermocouples containing platinum and rhodium, iridium-rhodium and iridium-ruthenium are in common use. Among a wide variety of miscellaneous uses for the platinum metals are: hypodermic needles and cautery points; osmiridium for the tips of fountain-pen nibs; electroplating applied to searchlight reflectors, watch-cases, trophies, medals and so forth; and palladium leaf for decorative purposes. Platinum is so ductile that it can readily be drawn into fine wires only one twenty-thousandth of an inch in diameter. It is stated that 'seven ounces of platinum could be drawn into a wire that would reach from New York to London'.

### *Occurrence and Production*

Platinum occurs in nature in metallic form and in combination with arsenic as sperrylite,  $\text{PtAs}_2$ . Crude platinum contains usually from 10% to 40% of varying amounts of osmium, iridium, rhodium, palladium, gold, copper and iron. Natural alloys of osmium and iridium, known as osmiridium and as iridosmine, are of considerably less importance as sources of the metals than crude platinum, but are recovered from some ores, such as those of the gold deposits of the Witwatersrand, Transvaal. Much palladium in the form of an arsenide or selenide is present with platinum arsenide in the Sudbury nickel-copper ores of Canada.

Most of the world's platinum is obtained from the Sudbury ores and from alluvial or placer deposits in the Urals, Colombia and Abyssinia (Ethiopia). A little is produced

from the basic igneous rocks, norites, of the Bushveld in the Transvaal.

The primary deposits of platinum, such as those of Sudbury and the Bushveld, are genetically related to basic igneous rocks of noritic type; and the platiniferous placer deposits of the Urals in the region of Nizhny Tagil are derived from the olivine-rich basic igneous rocks, dunites. Platinum occurs in the Urals within segregations of chromite in the dunites, but only a small amount is extracted by crushing the rock. Probably 90% of the Ural platinum production is dredged from alluvial deposits

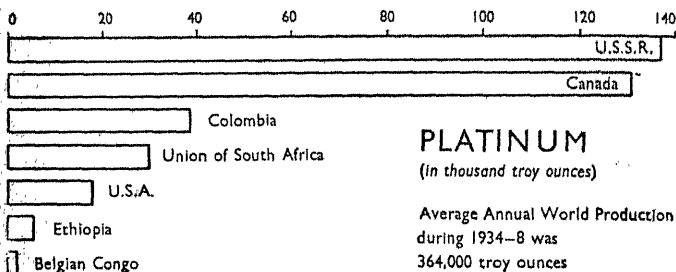


Fig. 18.

where the metal has been concentrated in stream gravels derived from the weathering of the dunites. The platinum deposits of Choco in Colombia, of Ethiopia, Alaska and Sierra Leone are also of placer type originating from basic igneous rocks.

In 1939 Sudbury in Canada produced 148,877 ounces of platinum, 135,402 ounces of palladium, rhodium and other metals of the platinum group. The combined output of platinum group metals from Sudbury is far in excess of that of any other country and is likely to remain so for many years. Fig. 18 refers to platinum only, not to the platinum group of metals.

In the Transvaal, selected parts of the Merensky Reef (discovered by Merensky, a well-known geologist) carry 6 dwt. of platinum over stoping widths of 30 inches, the product assaying 78% platinum, 16% palladium and 5% gold. In 1939 the Transvaal produced 59,000 ounces of platinum and 7,000 ounces of osmiridium. In the same year, 2,570 ounces of platinum and 12,890 ounces of palladium were recovered from the copper refinery of the Union Minière du Haut Katanga in Belgian Congo.

Since the slump period of 1932 the world production of platinum has increased from 177,000 troy ounces to 460,000 ounces in 1938, and it is estimated that in 1940 the production probably exceeded 600,000 ounces. About three-fourths of the production of the platinum group metals is platinum, the remaining quarter being palladium, iridium, and the others of the group.

During the five years ended in 1952, the average annual production of platinum metals in the chief producing countries was: Canada, 293,473 troy ounces; Union of South Africa, 151,197; U.S.S.R., 105,000; U.S.A., 30,655; Colombia, 28,600. For this quinquennial period, the average annual world production was 611,800 troy ounces of platinum metals, of which about two-thirds was platinum and one-third other platinum metals.

There are relatively few platinum deposits of economic interest in the world. The geographical distribution of the chief fields is shown in Fig. 31.

## POTASH

PLANT ash as a fertilizer has been used from early times, but it is little more than a century since scientists realized the importance of potash in the soil, and even half a century ago the principal use of potash was in dyeing and tanning.

in the manufacture of glass, porcelain, soap, matches and explosives. In the last few years, however, about 90% of the total potash production of the world has been employed as a fertilizer in agriculture. The name (pot ash) is derived from the iron pots used to evaporate the solutions leached from plant ashes and lime.

Potash as a fertilizer is most effective when employed in conjunction with proper amounts of other plant nutrients, such as phosphates and nitrates, the soluble potash assisting in promoting plant-growth and in forming the starches and sugar they require. The scarcity of potash during 1914-8 was probably, according to some authorities, the chief reason why vegetables in certain countries were of poor quality - they suffered from 'potash hunger' and 'potash starvation'. A number of potash salts, such as the sulphate, chloride and nitrate of potash, are in common use, but for agricultural purposes their composition is usually of less importance than their content of soluble oxide of potassium,  $K_2O$ .

In addition to agricultural and horticultural uses, potassium compounds have important applications in chemical industries, although the consumption is relatively small. The two most important for this purpose are caustic potash,  $KOH$ , and potassium carbonate,  $K_2CO_3$ , both of which are employed in the manufacture of soft soap, shaving soap, best-quality crystal-glass tableware, sculptured glass, church-window glass and other coloured glass. Potassium nitrate, although used mainly as a fertilizer, is also employed for meat preserving, in the petroleum industry, and for other purposes. The chlorate and perchlorate of potassium are strong oxidizing agents utilized for making explosives, matches, fireworks, and dyes. Potassium iodide is used in medicine and for photography, and potassium permanganate is an excellent oxidizer and anti-

septic. Potash is employed as a metallurgical flux for the recovery of magnesium and aluminium.

The metal potassium, which oxidizes rapidly on exposure to air, has very limited applications, and is used only where its effects are so different from those of the cheaper sodium that the more expensive metal is employed.

### *Occurrence and Production*

Potassium is present in most types of rocks in combination with other elements, chiefly with aluminium and silica in the form of potassium aluminium silicates, as in such primary minerals as orthoclase feldspar, muscovite and biotite micas, and others. The micas are very resistant to weathering, but orthoclase feldspar in certain circumstances becomes decomposed (see p. 58), and the potassium it contained is carried away in solution in streams to

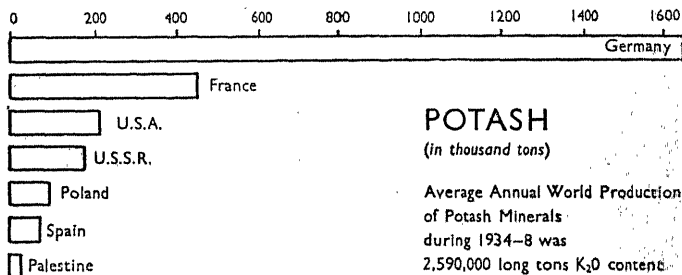


Fig. 19.

the sea. Other potassium minerals are also unstable, and contribute to the accumulation of potassium in sea-water. Under arid conditions the evaporation of sea-water in enclosed basins in past geological times resulted in the concentration of the chlorides and sulphates of potassium and magnesium as saline residues of great economic impor-

tance, as in the famous Stassfurt deposits of Germany (see p. 164), which formerly had a virtual monopoly of potassium salts. Similar deposits occur in Alsace; also in the Solikamsk region on the western slopes of the Urals in the U.S.S.R., which are now worked on a large scale.

In these saline deposits the chief potassium-bearing minerals are sylvite or potassium chloride,  $KCl$ ; carnallite, a potassium magnesium chloride; kainite, containing potassium chloride and magnesium sulphate; and polyhalite, a sulphate of potassium, magnesium and calcium. Of these, sylvite, carnallite and kainite are the chief sources of potash.

Another important source of potash is the water of salt lakes, such as the Dead Sea in Palestine, which during recent years has yielded annually considerable quantities of potash and bromine; and Searles Marsh in California, where natural brines unusually rich in potassium are treated on a considerable scale for the recovery of potassium salts and borax. Potash is recovered also from the brines of Saldura Marsh in Utah.

It will thus be clear that the potash industry derives its materials mainly from potassium chloride, in the form of the mineral sylvite, or which can be precipitated from natural waters containing potassium and chlorine. Carnallite is mined in Germany and Spain; langbeinite ( $K_2SO_4 \cdot 2MgSO_4$ ) in the U.S.A. and in the Ukraine; kainite in Ukraine; and alunite in Australia.

In the Atacama desert of Chile occur the world's chief deposits of natural nitrates, consisting mainly of sodium nitrate or 'Chile nitre' (see p. 145), but with potassium nitrate (saltpetre) also present; and, from the 50,000 tons of the mixed nitrates exported from Chile in 1939 to the U.S.A., about 7,000 tons of potash were extracted. Saltpetre occurs also as a saline efflorescence of organic origin on the sur-

face of soil, as it does in Central India, where it has long been worked. Another minor source of potassium is the mineral, alunite (alum stone), a potassium aluminium sulphate formed by the action of sulphuric acid on rocks in volcanic regions. Leucite, a potassium aluminium silicate which occurs as disseminated grains and crystals in some basaltic rocks, notably in basic lavas around Vesuvius and on the Leucite Hills of Wyoming in the U.S.A., has been mined in Italy as a fertilizer material and as a source of potash alum. The mineral glauconite, essentially a hydrous silicate of iron and potassium, which occurs extensively as grains in the Chalk Marl and Greensand of the Cretaceous in England and elsewhere, has been worked on a fairly small scale for its potash content. Artificial products like the kiln dust from the manufacture of Portland Cement, and blast-furnace flue dust, have supplied considerable amounts of potash; and valuable vegetable sources are kelp or seaweed, molasses, distillery waste, wood ashes, sunflower stalks and so forth.

In Australia the threatened interruption of potash fertilizer during World War II led to the establishment of a large-scale treatment plant to recover potash from the mud of Lake Campion, Western Australia, where reserves are estimated at 12 million tons of mud containing 60% of alunite (basic hydrous sulphate of aluminium and potassium). In 1947 a production of 34,731 tons of alunite containing 1,725 tons of potash was obtained from Lake Campion.

The total world production in 1937, the latest year for which reliable statistics are available, was equivalent to 3 million tons of potash, of which Germany produced 63%, mainly from the Stassfurt deposits; France, 16%, chiefly from Alsace; U.S.A., 9%; Poland, 3%; Palestine, 0.6%; and Spain, 0.4%. The geographical distribution of the chief potash fields is shown in Fig. 29.



During the five years ended in 1952, the average annual production of potash (in terms of its  $K_2O$  content) of the chief producing countries was: U.S.A., 1,184,185 long tons; Germany (Federal), 1,063,200; France, 848,533; Spain, 166,797; India, 2,800. For this quinquennial period, the average annual world production was 4,464,000 long tons.

The discovery in 1939 of potash in brine near Whitby, Yorkshire, at a depth of about 4,000 feet in an exploratory borehole for oil by the D'Arcy Exploration Company led to further investigation. It is probable that extensive potash deposits of great economic importance occur in this part of the old Zechstein Sea which in Permian times occupied northern Germany and extended over parts of north-eastern Yorkshire.

## QUARTZ

THE sand of beaches, the gravels of rivers, the sandstone and quartzite hill and mountain ranges are all composed mainly of quartz, one of the commonest of all minerals. In the form of sand it is employed extensively in mortar and cement; as a flux in the metallurgical industry; in the manufacture of glass and silica brick; as an abrasive, and for numerous other uses. And as a powder it is utilized in paints, scouring soaps, sandpaper, and as a filler. Quartzites are composed almost entirely of quartz, and sandstones may contain up to 80% and more of that mineral, and these two rocks are among the most widely used building- and paving-stones. Most granites contain over a third of their weight of quartz, and several other useful igneous rocks have an appreciable amount of the mineral.

Quartz is an oxide of silicon,  $SiO_2$ , and is of frequent occurrence in rock cavities in well-shaped crystals of

hexagonal prisms terminated by pyramidal faces. When the crystal is colourless, as is often the case, it is popularly known as rock crystal, and is employed in cheap jewellery and for making optical glass; amethyst is the clear purple or bluish-violet variety; rose quartz is rose-red or pink; cairngorm is smoky yellow to dark brown; and aventurine is quartz with a reddish-golden appearance due to the inclusion of innumerable minute spangles of other minerals such as hematite and mica.

Fragments of the colourless crystals are employed for making fused quartz used in the construction of special lenses, chemical equipment, and for the finest elastic fibres for suspending mirrors and beams in highly sensitive physical apparatus. Owing to its low coefficient of expansion, vitrified silica,  $\text{SiO}_2$ , is able to withstand sudden changes of temperature; it can be heated to redness and then plunged in cold water without cracking. Selected crystals of quartz cut parallel to their length into thin, wedge-shaped plates are valuable accessories for investigating the optical properties of minerals by means of the polarizing or petrological microscope.

The most fascinating and important use of quartz crystals is, however, in radio and telephone instruments. When a section of quartz is cut lengthwise from carefully selected crystals, and is then subjected to pressure, it becomes electrified, developing positive and negative charges on the opposite sides of the plate; and, conversely, electric charges applied to the plate cause it to become distorted. Quartz is thus piezoelectric, and use of this property is made in detecting extremely delicate changes of pressure in depth-sounding apparatus and for the measurement of instantaneous high pressures such as result from the firing of a gun or even the blow of a hammer.

During recent years the piezoelectric properties of

quartz have resulted in extensive use of the mineral for stabilizing the frequency of amplifier tube currents and in radio oscillators. The piezoelectric effect permits a small slab of quartz 'to vibrate or oscillate thousands or even millions of times each second'. It is the property of being able to maintain an extremely constant frequency, or rate of vibration, that endows quartz with its great value in radio applications. Nearly all broadcasting stations employ quartz control in order to maintain the frequency assigned to them.

Many substitutes for piezoelectric quartz have been tried. Rochelle salts are stated to be better than quartz; they are far less stable, but are being used in the U.S.A. as crystal filters and in zonal projectors in the telephone, radio, and electronic industries.

### *Occurrence and Production*

Quartz is among the most common and abundant of all minerals on the earth's surface and in the deepest mines. In most of the veins or lodes worked for metalliferous minerals it is the chief mineral present.

Crystals of quartz suitable for electrical purposes, such as for radio and telephone instruments, are, however, found in only few localities, the most important source being Brazil. Madagascar and Uganda have also produced small quantities. In all three countries it is interesting to note that the crystals are found in cavities or along joint-planes in quartzites which have been invaded by veins of granitic rock.

Reliable estimates of the tonnages of high-quality quartz crystals are difficult to obtain. The recent annual production is approximately 1,000 long tons, almost all from Brazil. More than half of the Brazilian output has been shipped to Great Britain in recent years.

## ROCK SALT AND COMMON SALT

COMMON salt is sodium chloride, and every person, we are told, requires about 12 lb. of it a year. Animals, especially herbivores, will travel long distances in search of a spring or salt lick, and in countries where it is scarce it has served as a basis of taxation under government monopoly to ensure monetary contribution from every family.

All readers will know that common salt is one of the most indispensable of all substances for food seasoning and preserving, but some may not have realized that with regard to quantity its chief use is in chemical industry, where it is employed in the preparation of a long list of chemicals, especially soda ash and caustic soda.

Soda ash (sodium carbonate) takes from 30% to 40% of the total output of salt for the manufacture of glass, soap, various sodium chemicals, and in the preparation of washing-soda and so forth; and large quantities are used for making sodium sulphate (salt cake) for the pulp and paper industry.

Caustic soda,  $\text{NaOH}$ , produced by the electrolysis of salt, is extensively utilized in the manufacture of soap, rayon and in the digestion of wood in the pulp and paper industry, in the purification of bauxite preparatory to the extraction of aluminium, and in the refining of petroleum.

Chlorine, made from salt, is widely used in bleaching pulp, paper and textiles; as a water sterilizer; for the manufacture of hydrochloric acid; and has numerous other applications, including the chlorination process in metallurgy.

Coal-tar dyes and products, the ceramic industry (for salt glazes and sewer-pipe glazes) and refrigeration agents consume large quantities of salt; and in its natural state, rock-

salt, it is employed for tanning hides, in fertilizers, stock feeds; and sodium chlorate made from salt is used largely as a weed killer. The metal, sodium, is produced from salt.

Pure salt is composed of 60.66% of chlorine and 39.34% of sodium. It is a non-conductor of electricity and is highly diathermic. It is thus used as blocks and lenses for experiments on radiant heat.

### *Occurrence and Production*

As it occurs in nature, salt is known as rock salt, or halite, and usually contains impurities such as calcium and magnesium sulphates and chlorides. It is found either as natural brines or in solid form, both the brines and the rock salt having the same or similar origin. In some warm countries salt is recovered by solar evaporation of sea-water in shallow ponds, but nature practises this process on a far more extensive scale in the Dead Sea in Palestine, the Great Salt Lake in Utah in the U.S.A., and in other dry regions. This was the case also in past geological ages, especially during the arid climate of the Permian and Trias, with the result that the sites of inland seas, intermittently supplied with sea-water, eventually became filled with rock salt and other salts that were in solution in the sea-water. The salt deposits of Cheshire, England, the famous Stassfurt deposits of Germany and many others were all formed in this way. Beds of rock salt range from a few feet to more than 300 feet, and exceptionally, as at Stassfurt, to over 1,000 feet in thickness, and are usually associated with other products from sea-water, such as gypsum and anhydrite. The ideal succession during the evaporation of sea-water, beginning of course with the most insoluble substance present, is: calcium and magnesium carbonate; calcium and magnesium sulphate; rock salt; and lastly the soluble salts of potash and magnesium from the mother liquor. This complete succession

is present at Stassfurt, Germany, and along the flanks of the Urals in the U.S.S.R.

The enormous extent of some of the salt formations is well exemplified by the Permian deposits of Kansas, Oklahoma, Texas, and New Mexico, which cover an area of about 100,000 square miles and have an average thick-

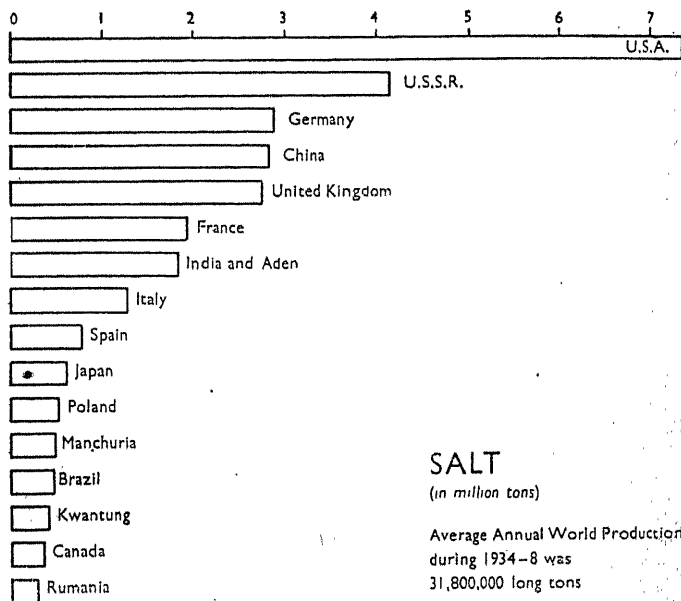


Fig. 20.

ness of some 200 feet. It is estimated that these deposits contain 30 million million tons of salt. When subjected to crustal pressure, beds of rock salt yield by plastic flow rather than by fracture or folding, and may be forced upwards, much like an igneous rock, to form great ridges such as the 'salt domes' of Texas.

World production (shown in Fig. 20) between 1934 and

1938 averaged nearly 32 million long tons a year, of which the U.S.A. yielded 23.4%; U.S.S.R., 13%; Germany, 9%; China, 8.8%; United Kingdom, 8.6%; France, 6.1%; India and Aden, 5.8%; Italy, 4%; and more than sixty other countries produced minor quantities.

During the five years ended in 1952, the average annual production of the chief producing countries was: U.S.A., 15,692,900 long tons; Great Britain, 4,072,165; France, 2,716,000; India, 2,512,560; China, 2,485,000; Germany, 2,290,650; Italy, 1,395,800; Spain, 1,095,377. For this quinquennial period, the average annual world production was 45,900,000 long tons.

In the United Kingdom 99% of the production is from brines and only 1% from mined rock salt. Cheshire provides approximately 80% of the salt produced in this country.

## SELENIUM

SOME of the uses of selenium are most fascinating. The selenium cell makes it possible to transmit photographs and sketches along a wire to illustrate papers and for television; to make records of sounds synchronous with moving pictures for cinemas; to construct automatic devices for lighting street lamps, buoys, electric signs, burglar alarms and for opening and closing doors without touching them; to enable the blind to read ordinary type by ear by means of the optophone; to register precisely the moment the runner touches the tape or the racehorse passes the finishing post; and to measure the density of smoke from chimneys and stacks.

All these recent and important applications result from the fact that when light impinges on selenium there is a lowering of its electrical resistance proportional to the

intensity of ordinary light. There are other substances in which the electrons are easily detached from the atoms, and are thus good conductors of electricity, but selenium is characterized by the fact that in the dark the electrons are not easily detached, whereas in visible light they are readily detached, from the atom.

When an object such as a runner, horse or motor-car intercepts a beam of light shining on a selenium cell, the shadow causes a change in the electrical resistance, which is instantaneously registered by actuating a relay; and in the same way street lamps are automatically lighted at dusk and extinguished at dawn as the result of the change in the intensity of light. The same principle applies to the registering of the degree of smoke density from chimneys and stacks.

Interesting as are these uses of selenium, the principal consumption of the element is for making ruby glass for red danger signals and for decolorizing glass, which otherwise would be tinted green owing to the presence of iron. For this latter purpose it has largely displaced manganese in recent years to give a pleasing pink tint instead of the objectionable green. Red enamels and glazes can be produced by the addition of selenium, and it or its compounds are employed also for vulcanizing rubber, in drugs, dyes and photographic materials, as a solvent for Bakelite and allied materials, for fire-proofing cables, and as an addition to non-odorous poisonous commercial gases, such as carbon monoxide, so that their stench will act as a warning. Notwithstanding all these applications, the total world tonnage of selenium used annually is only about 300 tons.

### *Occurrence and Production*

Selenium occurs in nature as selenides of lead, copper, mercury, and silver. These selenides are generally in minute



quantities intimately associated with other sulphide minerals so that selenium is always a by-product and never the chief ore mineral of the mines. Almost the entire production of selenium is obtained from copper refineries in Canada and the U.S.A., and some of the metal is also recovered from the flues of the sulphur burners used in the manufacture of sulphuric acid.

Between 1936 and 1939 the average annual world output of selenium was 305 long tons, of which Canada (Noranda and Flin Flon mines) averaged 165 tons, the U.S.A. 139 tons, and Northern Rhodesia 1 ton.

Usually, the production of selenium is returned in lb. avoirdupois. In 1952, the chief producing countries were: U.S.A., 687,380 lb.; Canada, 265,600; Sweden, 98,290; Japan, 58,694; Northern Rhodesia, 31,758 lb.

## SILLIMANITE GROUP

LITTLE more than twenty-five years ago, the minerals of the sillimanite group were almost unknown outside the geological world, but to-day they are in great demand for making high-grade refractories. Porcelain made from them is characterized by its high melting point, low coefficient of expansion, resistance to shock and low electrical conductivity, properties which render the porcelain eminently suitable for sparking-plugs, laboratory ware, thermocouple tubing and special refractory bricks used in electric and forging furnaces and cement kilns. Between 1922 and 1932 the Champion Spark Plug Company of the U.S.A. produced 350 million sparking-plug cores, using andalusite and dumortierite.

The chief commercial minerals in the group are the three aluminium silicates, andalusite, kyanite and silli-

manite, all of the same composition,  $\text{Al}_2\text{SiO}_5$ ; and the mineral dumortierite, a borosilicate of aluminium. They are all capable of withstanding high temperatures, and when fused in a furnace are converted wholly or partly into mullite,  $\text{Al}_6\text{Si}_2\text{O}_{13}$ . A recent use for kyanite is in the manufacture of refractory cements and for imparting toughness to glass.

### *Occurrence and Production*

Andalusite, kyanite and sillimanite are frequent accessory minerals in such metamorphic rocks as gneisses and schists, which have been converted into their present state by the intense alteration of the original shales and slates as the result chiefly of acid igneous action. Kyanite and andalusite are also found in granite pegmatites, but the most important workable deposits of these minerals are within schists and gneisses. There is strong evidence that these minerals, in part at least, may have been formed by emanations from acid igneous magma such as that which consolidates into granitic rocks. This is especially true of the dumortierite which is extracted from pegmatite and quartz veins in Nevada in the U.S.A., where mineralizing gases, or pneumatolytic action, have played an important role in the formation of the mineral.

Andalusite is being worked in sporadic segregations in quartz in California and with corundum in Nevada; and the mineral is recovered from rich andalusite sands in the western Transvaal. Kyanite is mined in several parts of the world, the most important deposits hitherto being in Singbhum and other parts of India, where more than 200,000 long tons of kyanite have been proved in one area. India possesses also the largest known deposit of sillimanite, in the Khasi Hills of Assam and at Pipra in the State of Rewa, these two sillimanite deposits being, unfortunately, not

easily accessible. Commercial deposits of dumortierite have hitherto been discovered only in Nevada, although the mineral is known to occur in small quantities in parts of India.

In 1935 India produced nearly 20,000 tons of 'kyanite'; the U.S.A. in 1940 yielded 4,000 tons of kyanite and imported from India 7,000 tons of it. Plans for extracting alumina from andalusite were stated to be well under way in 1940 in Sweden.

In 1952, India produced 26,882 long tons of kyanite and 5,076 tons of sillimanite; U.S.A. about 12,000 of kyanite; Union of South Africa, 19,176 of andalusite (including sillimanite); Kenya, 7,475 of mullite and 961 of kyanite; Bechuanaland Protectorate, 2,130 tons of kyanite.

## SILVER

'If gold be the king of metals, silver is the queen of them.' Ornaments of silver were found in the royal tombs of Chaldaea, built in the fourth millennium B.C., and throughout the ages the pleasing colour it retains untarnished in atmosphere free from sulphurous gases, its malleability and ductility, made it next to gold the favourite metal for ornamental purposes. Indeed, in some countries, as in ancient Arabia and Germany, silver was more valuable than gold, and as recently as the seventeenth century in Japan the two were equal in price. The value of the metal depends, however, on supply and demand, and as most of the world's silver now comes from lead, zinc and copper mines, and there has been great demand for these metals, the increased production of silver resulted in considerable decrease in the price of the metal. Five hundred years ago

gold was ten times more valuable than silver; a hundred years ago it was almost sixteen times; in 1900 it was thirty-three times; and at present gold is about one hundred times the value of silver. To be born 'with a silver spoon in the mouth' is an allusion to the once-high cost of silver table-ware.

Although there have been no rushes for silver comparable with gold rushes, yet much romance is connected with the fabulous wealth in the form of silver brought to Europe by British and Spanish galleons across the Spanish Main from Mexico and Peru. It was the search for El Dorado, the fabled land of gold, that led the Spaniards towards the New World. In Mexico, at Arazuma, nuggets of almost pure silver more than a ton in weight were found, and phenomenally rich silver ores were discovered in that country at Santa Eulalia in Sonora. In later times, during the past century, extraordinarily rich silver ores were found in Nevada and Colorado in the U.S.A. The famous gold-silver ores of the Comstock Lode in Nevada, now nearing exhaustion, produced from a single shoot of ore more than £20 million of silver in three years.

The chief use of silver is for monetary purposes, and about two-thirds of the total production is so employed, the outstanding consumer of the metal for coinage being the U.S.A. It was estimated that in January 1941 the amount of silver in existence throughout the world for monetary requirements was 6,000 million troy ounces, of which a little more than half was in the U.S.A. It is known that large quantities of silver coinage are being hoarded in India and China, but much of the metal from coinage is recovered whenever the intrinsic value of the silver exceeds that of the coin. Demonetization of silver, which has been going on for many years, has caused many governments to interfere with the free movement of the metal.

In October 1942 the United States Defence Plant Corporation allotted 34,000 tons of Treasury silver for use in war industries, and about half of that tonnage had been used by the end of 1942 in bus bars and windings of the electrical plant installed in ten new war factories producing magnesium, aluminium, graphite, and synthetic phenol.

Pure silver, like pure gold, is too soft for coinage, ornaments, plate and jewellery, and the metal is usually alloyed with copper to harden it. The alloy used before 1940 in Great Britain in silver coins was 500 silver, 400 copper, 50 zinc and 50 nickel. A shilling thus contained less than three pennyworth of silver. In the U.S.A. silver coins are of 900 fineness – that is, 900 parts silver and 100 parts copper. The British standard for silver in plate and jewellery is 925 silver and 75 copper.

About a quarter of the world's silver is consumed in the arts and industries. Its ductility is such that 1 gram of the pure metal can be drawn out into a wire more than a mile long; and it is so malleable that it can be beaten into leaf only one four-thousandth of an inch in thickness. The addition of a little copper to silver lowers its melting point, prevents it from blistering on solidification, and makes it harder without affecting materially its colour and malleability. Electroplated ware is made by depositing pure silver on a base of 'nickel silver' alloy containing nickel, copper, and zinc. In the presence of sulphurous gases in the atmospheres of industrial towns a brownish to black tarnish of silver sulphide forms on silver; and the sulphur in egg rapidly tarnishes a silver-plated spoon.

An important use of silver is in photography, especially since the development and rapid expansion of the motion-picture industry, in which many millions of feet of films are used annually. It is the unique and instantaneous reaction of the halides of silver on exposure to light that makes the

metal virtually indispensable for films, plates, and photographic printing paper.

Various compounds of silver are used medicinally, particularly the nitrate. It is claimed that one part of silver in 10 million parts of water will destroy the more common pathogenes and 'should be used more extensively in public bathing pools'. Among many miscellaneous uses are: silver solders, as in refrigerators and aircraft construction, dental amalgams, silvered mirrors, silver oxide for imparting a yellow colour to glass; and, since silver is the best conductor of electricity (and also of heat), it is employed in many electrical instruments.

### *Occurrence and Production*

Silver occurs in nature in the form of metal and in combination with other elements. Some argentiferous minerals are not stable under certain natural conditions, and there is strong evidence that most, but not all, the metallic silver found in deposits is not of primary origin, but has been formed by the alteration of pre-existing silver minerals. This secondary native silver may occur in zones extending to many hundreds of feet below groundwater level, and rich patches, or bonanzas, of the metal have been mined in Mexico, Bolivia, Peru, the Comstock Lode of Nevada in the U.S.A., in the upper workings at Broken Hill, New South Wales, and in other countries. There is little doubt, however, that in a few localities the mineral is of primary origin, as, for example, in the steam vesicles of the copper-bearing lava flows of Lake Superior.

Silver forms a primary natural alloy with gold in the mineral electrum, and is also an essential constituent of the important gold tellurides (see p. 84). Much of the world's silver is recovered during the treatment of gold ores. In the chief goldfield of the world, the Rand in Transvaal, South

Africa, the gold contains an average of about 10% silver.

The chief source of the world's silver is the silver sulphide mineral, argentite,  $\text{Ag}_2\text{S}$ , which is present to some extent in almost all galena, the chief ore of lead, and often in appreciable amounts. The ruby silver minerals, proustite and pyrargyrite, are of minor importance as sources of silver,

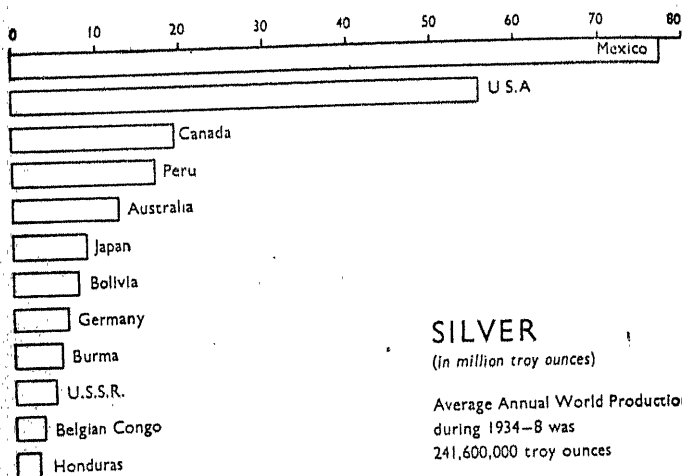


Fig. 21.

but the mineral cerargyrite, or horn silver,  $\text{AgCl}$ , which is prevalent in the upper parts of some lead and silver mines, contributes to the supply of the metal. At Broken Hill, New South Wales, and in the rich lodes of Comstock and Tonopah in Nevada, U.S.A., cerargyrite yielded large quantities of silver.

More than half of the world's silver is obtained not from silver mines, but from argentiferous lead, zinc and copper ores as a by-product. It has been estimated that silver-

bearing ores which produce 91% of the world's silver also produce 85% of the world's gold, 69% of the lead, 66% of the copper, and 46% of the world's zinc.

Silver is chiefly confined to veins or lodes formed originally at relatively shallow or intermediate depths. It often occurs with galena in lead lodes and replacement ore-bodies, such as those of the Tintic and Park City districts of Utah and Coeur d'Alene in Idaho. Formerly argentiferous lead ores were mined extensively in North Wales, and in the north and north-west of England. Many lead-zinc ores contain much silver, and among famous producers of lead, zinc and silver are Broken Hill, New South Wales; Sullivan Mine in British Columbia, the largest of its kind in the world; and Bawdwin Mines in Burma. At Bingham in Utah and in mines in Peru and elsewhere silver is recovered as a by-product during the treatment of copper or of lead-zinc ores. About  $2\frac{1}{2}$  million ounces of silver are recovered annually by the International Nickel Company of Canada, mainly from the Sudbury copper-nickel ores.

Among the richest silver ores ever located are those of the Cobalt district in Ontario, where rich silver veins, sometimes carrying masses of native silver weighing up to 1,600 lb., were exposed on the surface. The silver is in association with cobalt and nickel ores, but the production from this once-flourishing field has now greatly declined.

Mexico has for a long period of years been a leading producer of silver; and in the famous mines of Cerro de Pasco in Peru rich silver deposits occur in complex lead and copper ore. Formerly the Cerro de Pasco deposits were worked chiefly for silver, but in the deeper zones copper ore is the main product. The Potosi mines in Bolivia have probably produced more silver than any other single mining camp in the world; it was estimated in 1940 that these mines had yielded more than 1,000 million troy ounces of



silver since 1545. The silver output of Bolivia from 1545 to 1938 was estimated to be 53,000 tons of the metal; and of Peru, a total of 47,500 tons. About 75 % of the world's silver is produced from the western mountain belt of North and South America, including the Rocky Mountains; and the mountains of Mexico, Central America, Colombia, Peru, Bolivia, and Chile.

More recently, important developments have taken place in the 'dry belt' of Cœur d'Alène region in Idaho, where the Sunshine Mine is now the second largest silver producer in the world.

During the five years ended in 1952, the average annual production (in terms of metal) of the chief silver-producing countries was: Mexico, 50,053,466 fine troy ounces; U.S.A., 38,819,540; Canada, 21,231,770; Peru, 13,821,187; Australia, 10,560,420; Bolivia, 6,995,470; Belgian Congo, 4,267,308; Japan, 3,736,547; Honduras, 3,379,620. For this quinquennial period it is estimated that the average annual world production (exclusive of U.S.S.R. etc.) was 171,400,000 troy ounces.

The geographical distribution of the chief silver fields is shown in Fig. 31.

## STRONTIUM

THE intense red or crimson colour in fireworks and flares is imparted by strontium salts, especially by strontium nitrate, for which no effective substitute is known for this purpose. It is not, however, in pyrotechnics that strontium finds its principal use, but in the beet-sugar industry. Strontium hydroxide is employed for the recovery of sugar from sugar-beet molasses, because it readily combines with the sugar

to form a disaccharate from which sugar is extracted by treatment with carbon dioxide.

Small amounts of strontium are used for chemical and pharmaceutical purposes, as a filler in certain rubber goods, for special paints and as a flux and desulphurizer in the manufacture of steel.

### *Occurrence and Production*

The two chief strontium minerals are the sulphate, celestite,  $\text{SrSO}_4$ , and the carbonate, strontianite,  $\text{SrCO}_3$ , and they are the only sources of strontium salts used in industry, celestite being the chief.

Celestite generally occurs as veins, nodules and irregular layers or pockets in sedimentary rocks such as the Keuper Marls of Gloucestershire, where the mineral was probably deposited from waters of an inland sea during a period of dry climate. Deposits of this type, which usually contain gypsum and anhydrite, are worked in shallow pits at Yate near Bristol, which supply the bulk of the world's production of celestite. In Sicily celestite is associated with sulphur and gypsum, and may have been formed as the result of submarine solfataras. In Ontario, Canada, celestite occurs in veins formed probably by the action of hot mineralizing solutions.

Strontianite often occurs with celestite, and is usually the result of the decomposition of celestite.

During the quinquennial period 1934-8 the average annual production of strontium minerals was about 7,000 tons, of which the United Kingdom yielded 95%, mainly from the Yate district near Bristol. Since 1884 the total output of celestite from Gloucestershire has been about half a million tons.

During the five years ended in 1952, the average annual production of celestite in the United Kingdom was 8,660

long tons, and in Mexico, 1,365 tons. Pakistan produced, in 1952, 431 tons of celestite and Tunis 399 tons in 1951, but only 30 tons in 1952.

## SULPHUR AND PYRITE

'A NATION's consumption of sulphur is a measure of its industrial progress.' This statement is pregnant with truth, for sulphur, or brimstone as it is sometimes called, is one of the most widely used elements in modern industry, and few important manufacturing processes do not employ it in some form or other. This commanding position of sulphur as an essential raw material is due to the fact that sulphuric acid is the 'most important single commodity in the chemical industry'. It might be added also that this acid is the chief natural reagent which brings about far-reaching changes in the mineral world.

Sulphuric acid is obtained from three chief sources: from pyrite, also known as iron pyrites,  $\text{FeS}_2$ ; from native or natural sulphur; and from the sulphur recovered from smelter and other industrial gases. In Europe most of the sulphuric acid is manufactured from pyrite, whereas in the U.S.A. over 60% of the sulphuric acid production is derived from native sulphur. The chief consumer of sulphuric acid is the U.S.A., which used more than 8,100,000 long tons in 1940, 24.7% of it in the manufacture of fertilizers, 13.8% for petroleum refining, 13.1% in the iron and steel industry, 11.9% as chemicals, 9.8% for coal products, 7% for non-ferrous metallurgical processes, 6.2% for paints and pigments, 5.1% in the manufacture of rayon and cellulose film, and the remainder for miscellaneous purposes, including explosives and textiles.

Sulphur-dioxide,  $\text{SO}_2$ , finds its chief application in the

paper industry, which ranks third among industries according to the amount of sulphur consumed. About 250 lb. of sulphur is needed to make 1 ton of sulphite pulp.

Sulphur, in the form of dust and as spray material, is used as an insecticide and fungicide to control pests on fruit and field crops, and also as a weed-killer. Large amounts of sulphur are consumed in making vulcanized rubber goods; and acid-proof cement with up to 40% sulphur is an important product. There are other numerous uses for sulphur and its compounds.

Pyrite is employed mainly in making sulphuric acid, though large tonnages are now utilized for the production of sulphite and brimstone. About 2 tons of high-grade pyrite are required to make as much sulphuric acid as

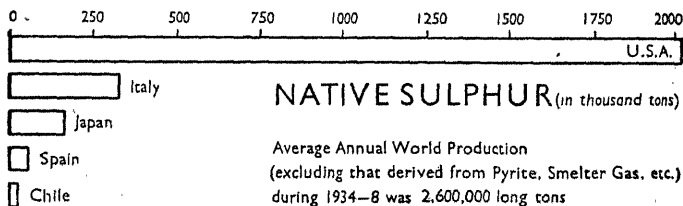


Fig. 22.

could be made with 1 ton of sulphur. The oxide of iron resulting from the roasting of pyrite to rid it of sulphur is, within recent years, used for the manufacture of pig iron and steel.

### *Occurrence and Production of Sulphur*

The element is formed in nature at and near the craters of volcanoes, especially where the sulphurous gases, hydrogen sulphide and sulphur dioxide, are being emitted, for when these two gases combine, sulphur and water are

deposited. The element also results from the incomplete oxidation of hydrogen sulphide, and a large deposit formed in this way is worked at Hokkaido in Japan, where the sulphur occurs in clays within an old crater lake. Similarly formed deposits are mined in the volcanoes of the Chilean Andes.

In the neighbourhood of active or extinct hot springs, in the tufas or other adjoining porous rocks like volcanic tuffs, sulphur is of very common occurrence. Hot sulphurous waters may replace limestones to form native sulphur, gypsum and other sulphur-bearing minerals. Sulphur bacteria are capable of oxidizing hydrogen sulphide and of storing sulphur in their cells, and some authorities believe that bacteria can also reduce sulphates to liberate hydrogen sulphide to obtain sulphur.

The principal sulphur deposits of the world are those of the U.S.A. and Sicily. These occur in sedimentary rocks in close association with limestone and the sulphates of calcium (gypsum and anhydrite), and gaseous or solid hydrocarbons are frequently present. The most productive of all such deposits are those in the cap-rocks overlying great plug-like intrusions of rock salt, or salt domes, which are common in Texas and Louisiana in the U.S.A. Above a single salt dome in Texas there are stated to be 45 million tons of sulphur, and recent researches point to the possibility that the sulphur in these deposits is due to the activity of anaerobic bacteria, but this is not universally accepted. The sulphur in these deposits is mined by the Frasch process, involving the introduction into the sulphur beds of superheated water at a temperature of  $175^{\circ}\text{C}$ ., which is higher than that of the melting point of sulphur,  $115^{\circ}\text{C}$ ., the molten sulphur being then conducted into bins where it solidifies. The superheated water is under pressure, and compressed air under a pressure of 400 lb. is forced down an

inner pipe to push the sulphur to the surface.

The Sicilian sulphur deposits cover several hundred square miles, are interstratified with limestone, gypsum, bituminous marls, clay and sandstones of Tertiary age, and average about 25% of sulphur.

World production of sulphur in 1940 was estimated to be about 3,600,000 tons, of which 75% was mined by the U.S.A., 10% by Italy, mainly from Sicily, 4% by Japan and 2% by Spain, Chile and the Netherlands East Indies. The remaining 9% was obtained almost entirely as a by-product from industrial gases in various countries, and from Spanish and Norwegian pyrite.

During the five years ended in 1952, the average annual production of sulphur (excluding that derived from pyrite and smelters) from the chief producing countries was: U.S.A., 5,075,560 long tons; Italy, 1,601,800; France, 165,000; Japan, 102,050; Spain, 41,853. For this quinquennial period, the average annual world production of sulphur, excluding that derived from pyrite and smelters, was 7,048,400 long tons.

### *Occurrence and Production of Pyrite*

Pyrite derives its name from the Greek word meaning 'fire', in allusion to the emission of sparks when the mineral is struck sharply with a metallic implement. It has some resemblance to gold in colour, and is colloquially known as 'fools' gold'. It is recorded that pyrite, in mistake for gold, was the first mineral shipped from America to England.

When pure it contains 53.4% sulphur and 46.6% iron, and is one of the commonest of all sulphide minerals, being present as small cubic crystals or grains in most types of rocks. It can be formed in nature under a very wide range of temperature and pressure conditions, but the most im-

portant commercial ore-bodies originated by deposition from hot mineralizing solutions.

Spain has the largest deposits of pyrite of any country. According to estimates published in 1926, about half the world's reserves of this mineral occur within the Province of Huelva in the south-west of Spain, the famous Rio Tinto mines alone accounting for nearly a quarter of the world's potential supplies. The pyrite belt extends from the Pro-

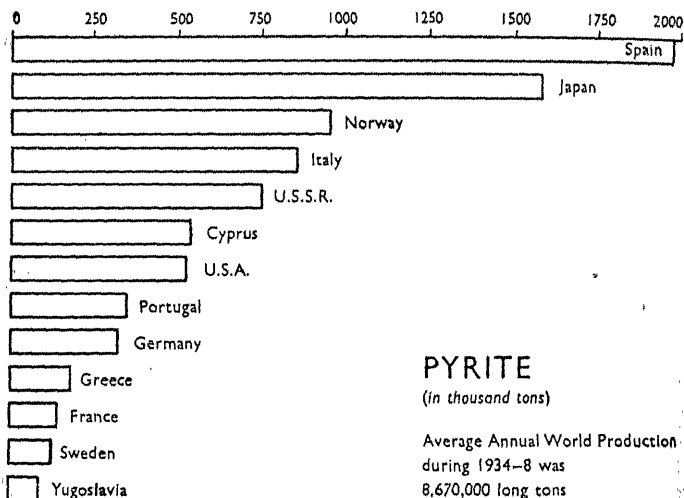


Fig. 23.

vince of Seville westwards into Portugal, and the ore-bodies in this belt are usually in the form of great lenses, which often lie at the contact between slates and intrusive porphyries. The ore is massive, and at Rio Tinto averages about 48% sulphur with minor amounts of copper, lead and zinc. One of the ore-bodies at Rio Tinto is more than half a mile long, in places over 800 feet wide, and has been proved to

persist in depth for at least 1,500 feet below its outcrop. The origin of these Spanish pyritic bodies is controversial, but strong evidence has been adduced in recent years supporting the theory that they were formed by hydrothermal replacement of porphyry and slate by hot tenuous ascending mineralizing solutions.

Many pyritic deposits yield valuable by-products such as gold and copper, the absence of which, in some cases, would render the ore-body unprofitable.

World production of pyrite in 1937 was approximately 10 million tons a year, yielding 4,300,000 tons of sulphur as compared with 3,600,000 tons of that element produced from deposits of native sulphur. For the quinquennial period 1934-8 the relative production was as follows: Spain, 23%; Japan, 18%; Norway, 11%; Italy, 10%; U.S.S.R., 9%; Cyprus, 6%, and U.S.A., 6%.

Before 1932 Spain produced more than half of the annual world output, but civil war and other causes resulted in a considerable decrease in output during the next decade. The geographical distribution of the chief pyrite and sulphur fields is shown in Fig. 29.

During the five years ended in 1952, the average annual production of the chief producing countries (including cupreous pyrites) was: Japan, 1,887,348; Spain, 1,566,745; U.S.A., 952,040; Italy, 913,540; Norway, 715,960; Portugal, 646,250; Cyprus, 635,165; Germany (Federal), 472,483; Sweden, 401,764; Canada, 297,200. For this quinquennial period, the average annual world production (excluding U.S.S.R. and satellites) was 9,508,200 long tons.



## TALC AND SOAPSTONE

TALC is probably the first mineral with which man comes into contact on entering this world. It is the toilet preparation in talcum powders and many face powders, but the quantity so used, although not the value, is very small compared to the amount used in industry.

It is one of the softest of minerals, can easily be scratched with a finger-nail, has a remarkably greasy or soapy feel, and on that account the massive and frequently impure substance has been termed 'steatite' or 'soapstone'. It was used during the Stone Age as a conveniently soft material for carving figures, and later, when its fire-resisting properties became known, for making pots, and it is still sometimes known as 'potstone'.

The pure or almost pure mineral, talc, is a hydrous magnesium silicate,  $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$ , but the variety, soapstone, frequently contains considerable quantities of impurities and, in fact, the hydrous aluminium silicate, pyrophyllite,  $\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$ , which has properties rather similar to those of talc, is for commercial purposes generally included in the statistics relating to talc.

Talc has low conductivity to heat and electricity, is fire-resisting, hardens when heated to a high temperature, is undecomposed by acids, and in powdered form is white in colour. These valuable properties account for its wide use in industry.

About 90% of talc production is marketed in a ground form, mostly after passing through a 200-mesh screen, and ten years ago nearly half of the total output was consumed by the paint industry, which is still the major consumer, now using 25% of the production; but substitutes like

barytes and china-clay and other substances are replacing it in some paints. Both the fibrous and flake varieties of talc are employed as extenders in paint, the fibrous form, owing to its bonding effect on the paint film, being widely used in cold-water paint or distemper, as a pigment in covering indoor plaster.

In the last decade there has been a marked increase in the utilization of talc in ceramics for the manufacture of tiles, electrical porcelain, and table-ware. The hard-baked form of talc, known commercially by the misleading name, 'Lava', has long been employed for the tips of gas-burners, and is now used extensively for electrical insulation and for refractory purposes.

Approximately 22% of talc production goes into the manufacture of paper. In 1940 more than half this amount was required for 'roofing paper' in which the mineral serves both as a filler and as an inert, durable, fireproof coating; and to coat the surface of 'composition' roofing so that it will not stick when rolled. The poorer grades and off-colour talc are employed for roofing purposes, and the better grades for high-quality paper in which they serve to 'load' the paper and, as talc is retained in the cellulose fibre better than china-clay, for glazing and in blotting-paper.

It is used as a filler in a wide range of industries, especially in the rubber trade, which consumes about 10% of the total production, mostly as a filler, but some as a dusting agent to prevent sticking; also as a filler in asbestos products, composition flooring, wall plasters, oilcloths, polishes, soaps, plastics, and textile fabrics.

Toilet preparations take only 3% of the world production, and foundry facings, where it is used as a dusting agent and to coat moulds, about 2%. Among a great number of minor uses of the powdered mineral are these: for packing parachutes to prevent rotting from the effects of moisture;

as a lubricant in greases; on the inner tubes of rubber tyres; in rubber gloves; and as a covering for boilers and steam-pipes.

In the massive form, soapstone, it is utilized as slabs for electrical switchboards, acid-proof table-tops, sanitary appliances, and laundry tubs and sinks. 'French chalk' is soapstone or steatite, used by tailors for marking cloth. The best quality is used for crayons and pencils.

### *Occurrence and Production*

The chief deposits of talc and soapstone occur in altered magnesia-rich basic igneous rocks such as peridotites and dunites, or in metamorphosed magnesia-rich calcareous rocks such as dolomite marble and magnesian limestone. The purest talc deposits frequently occur in association with dolomite and marble, where the talc owes its origin to the hydration of the magnesian silicate minerals which were formed during the earlier metamorphism of the carbonate rocks. The mineral magnesite is also an alteration product of these rocks, and may occur with the talc. Most authorities agree that this hydration was not the result of atmospheric weathering, but was brought about mainly by hydrothermal solutions or hot magmatic waters; and this is also the more generally accepted theory for the formation of talc from the magnesium-bearing minerals in the basic igneous rocks.

The talc deposits in altered basic rocks such as serpentines are usually of poorer quality than those in calcareous rocks, and the talc in the former is quite clearly a secondary mineral formed later than the host rock.

A third environment in which talc is sometimes found is mica schists where it occurs as thin beds, or interlamina-tions which may represent replacements of magnesian limestone in the schistose rocks. The largest talc deposit in

Europe, on the northern slope of the Pyrenees, occurs as beds in mica schist, but it is significant that the talc contains inclusions of dolomite and of granite. Massive soapstone is generally found near the margins of ultrabasic intrusions; and pyrophyllite chiefly in highly metamorphosed rocks, especially in acid volcanic tuffs.

During 1935-7 the total world production of talc, including soapstone and pyrophyllite, amounted to about half a million tons annually. The U.S.A. supplied about 44%, Manchuria 16%, France and Italy 11% each, Norway 5%, India 4%, U.S.S.R., Canada, Germany, and Sweden 2% each, and Spain 1%.

In 1952 the chief producing countries of talc (including steatite and pyrophyllite) were: U.S.A., 644,858 long tons; Japan, 313,358; France, 106,000; Italy, 77,600; Norway, 63,060; Canada, 43,184. The world production (excluding U.S.S.R. and satellites) was about  $1\frac{1}{2}$  million tons.

## TANTALUM AND NIOBIUM

TANTALUM was first used commercially in the filaments of incandescent electric lamps, and between 1905 and 1911 it replaced almost entirely the carbon filament lamp, and later was itself superseded by the more efficient tungsten filament. Where, however, strong vibration occurs near the light source, tantalum filament is still utilized because of its superior toughness to tungsten, but only with direct electric current, for it gradually disintegrates when transmitting alternating currents.

Metallic tantalum may become one of the most useful of rare metals owing to its great tenacity, ductility, tensile strength, hardness, and particularly to its remarkable resistance to corrosion by most acids. Columbium (nio-

bium) became one of the most critical metals during the Second World War. It inhibits the air-hardening property in 4% to 6% chromium steels of low carbon content. Corrosion-resisting steels containing 0.5% to 0.8% of columbium are used in aircraft exhaust systems, supercharger systems, and engine parts exposed to high temperatures. Their uses are increasing, as, for example, in the recent employment of tantalum in vacuum tubes for radio broadcasting and receiving, the tantalum being utilized for the plate and grid, especially in power tubes. Because of its extraordinarily anti-corrosive properties, tantalum is employed in chemical equipment and in the manufacture of surgical and dental instruments such as hypodermic needles and spatulas; and for making pen-nibs, and spinnerets used in the preparation of artificial silk. The metal is for certain purposes superior to platinum as a cathode, and owing to its capacity for absorbing gases like hydrogen, oxygen and nitrogen it is employed as a 'getter' or absorber of the last traces of the gases remaining after the mechanical evacuation of radio-valves, thus producing a high vacuum. The electrolytic valve action of tantalum is used in the trickle-charging of batteries.

Ferro-tantalum alloy, with 60% to 70% of tantalum, is used in the manufacture of springs and saws, and there are in service many alloys of tantalum with iron, nickel, tungsten, molybdenum and chromium, particularly where resistance to corrosion is of importance. Certain high-speed tools contain small percentages of tantalum and niobium.

Tantalum carbide is one of the hardest substances known; it is almost as hard as diamond and has a high melting point.

Niobium (columbium) is now used as an alloy in weldable high-speed steels and for making certain stainless chromium steels. It has a hardening effect on steel and, like

tantalum, it can be spot-welded to itself or to other metals.

The remarkable properties of metallic columbite for gas absorption have resulted in its increasing use in radio-transmitting valves. A highly sensitive heat-detecting device, the 'balometer', which has a columbium nitride surface, was used extensively during World War II.

Certain stainless steels and non-ferrous alloys containing columbium are becoming of great importance in the manufacture of components for jet and other engines for aircraft.

### *Occurrence and Production*

Almost the only sources of the metals are the two minerals, tantalite,  $(\text{FeMn})\text{Ta}_2\text{O}_6$ , and columbite,  $(\text{FeMn})\text{Cb}_2\text{O}_6$ , which form the end members of an isomorphous series which grade insensibly into one another. Those varieties of tantalite which are rich in manganese are classed as manganotantalite, one of the most important sources of tantalum in the Western Australian deposits.

These minerals, like those of tin, are characteristically associated with granitic rocks, especially with granite pegmatites and quartz veins traversing granite and adjacent rocks. They are thus frequently found with cassiterite or tinstone, wolfram, tourmaline, and occasionally with beryl, either in the solid rock or in the alluvial deposits derived from it.

The most productive tantalum deposits are those of the Pilbara district in Western Australia, which in former years supplied the world with all the tantalum it required, but within recent years the output has on occasions been exceeded by that of Belgian Congo. Small amounts of tantalite come from Uganda, the Erongo tinfields of South-West Africa, and Brazil.

Columbite (also called niobite) is obtained principally from the tin deposits near Jos in Northern Nigeria, and

small amounts from the granite pegmatites of the Black Hills of South Dakota in the U.S.A.

For the four years ended in 1940, Nigeria produced an average of 516 long tons of columbite. Belgian Congo produced 118 tons in 1937, but only 60 tons in 1938 of tantalite and columbite; Western Australia, 21 tons of tantalite in 1937; Uganda, 28 tons in 1937, 9 tons in 1938, but only 1 ton in 1939; and a total of 17 tons were produced in 1939 in South-West Africa, Brazil and Southern Rhodesia.

The average annual world production of tantalite during 1937-9 was 150 tons, and of columbite 500 tons.

In 1947 the three important producing countries of tantalite were: Belgian Congo, 139 tons of concentrates; Brazil, 32 tons; and Southern Rhodesia, 15 tons of concentrates. Over 90% of the world production was imported by the U.S.A.

Nigeria's production in 1952 of 1,293 tons of columbite represented over 90% of the world's supply, other than what may be produced in the U.S.S.R. Small amounts of columbite were mined also in Brazil, Belgian Congo, Uganda, Union of South Africa, and Malaya, where the mineral occurs sporadically.

## TELLURIUM

No important uses have hitherto been found for tellurium, and the total world consumption of the metal is little more than 30 tons a year. Until a few years ago it was a difficult metal to deal with, one of the difficulties being that workers were apt to acquire the remarkably objectionable 'tellurium breath'. Many of the difficulties have been overcome by electrodeposition of the metal. Small amounts of tellurium are now used as radio rectifier or crystal detector,

as a corrosion-resistant surface coating on such metals as magnesium; and alloys of aluminium and tellurium are said to possess high tensile strength. The metal is employed to a small extent in giving blue and brown tints to glass and porcelain; and silverware dipped in a solution of tellurium chloride assumes a dark 'platinum finish'. It has also been found recently that the addition of a little tellurium produces a hard and durable rubber for hose and cable coverings; and the metal has minor applications in photography, chemistry, and medicine. The addition of 0.05% of tellurium to lead increases resistance to frost when employed for water-pipes.

### *Occurrence and Production*

Tellurium is found in nature in combination with other elements, mainly as tellurides of gold, silver and a few other metals. The chief gold telluride is the mineral calaverite,  $(\text{AuAg})\text{Te}_2$ , which at Cripple Creek in Colorado, and at Kalgoorlie in Western Australia, has yielded large quantities of gold. At Cripple Creek the gold tellurides were formed by ascending mineralizing solutions which were not under relatively high temperature and pressure conditions. Little or no attempt, however, has hitherto been made to recover the tellurium during the treatment of these gold ores. The mines at Cripple Creek were closed for the duration of the Second World War.

The production of tellurium metal is obtained wholly from the slimes formed during the electrolytic refining of copper; the amount recovered from refining blister copper ranges from about 3 lb. to 67 lb. per 100 tons of copper. The chief copper ores yielding tellurium are those of Butte in Montana, and Noranda in Quebec.

Fifteen years ago the total annual world production of tellurium was less than 1 ton, and between 1936 and 1939 it



averaged nearly 33 tons annually, of which Canada and the U.S.A. contributed almost equal amounts. No production of the metal is recorded from any other country.

In 1952, the U.S.A. produced 189,076 lb. of tellurium and Canada 13,700 lb.

## TIN

TIN was certainly one of the first metals used by man, and centuries before the Roman invasion of Britain Phoenician traders from Tyre and Sidon brought their ships to Cornwall in search of tin. It happens that cassiterite, the chief mineral from which the metal is extracted, possesses physical and chemical properties which enable it to withstand weathering processes to such a degree that it remains unaltered throughout geological ages, so that even in the oldest stanniferous gravels the mineral is in the same state as when originally formed. It was from the gravels of the stream-beds in Cornwall, where, by virtue of its greater density than the sand, it had become concentrated by natural agencies, that the mineral was obtained in ancient times; and the fact that this oxide of tin could be reduced readily to the metal by heating with wood charcoal in primitive furnaces built of stone and clay made tin available to man long before he was capable of smelting iron.

Now it happens that in parts of Cornwall tin and copper minerals occur together, and when in ancient times these minerals were smelted as one charge, the yellow alloy produced was found to be harder than either tin or copper, both of which are soft metals, and was thus more useful for making implements than either of the softer metals. This appears to be the history of the accidental discovery of ancient bronze, which contained 88% copper and 12% tin;

and the lesser skill required for making it than for producing iron suitable for implements offers a reasonable explanation why the 'Bronze Age' preceded the 'Iron Age'.

It was not, however, until the nineteenth century that tin was employed in industry on a large scale. In 1800 the total world production of the metal was less than 9,000 long tons, whereas in 1900 it had increased to 75,000 tons, and by 1940 had reached 238,000 long tons, or more than three times what it was about fifty years ago. This rapid increase was due mainly to the extensive use of 'tin' cans throughout the world as containers of preserved fruit, meat, fish, petrol, paraffin and so forth. The once-familiar statement that in the U.S.A. 'they eat all they can, and can all they can't' has lost its meaning, for a great deal of what they eat, and much of the food consumed by other nations, is now from 'tin' cans.

Although the tonnage of tin used for making tinplate for the canning industry is now the principal single use of the metal, there is actually very little tin in the ordinary 'tin' can. Less than  $1\frac{1}{2}\%$  of the weight of an empty 'tin', such as is used for fruit, meat, biscuit and so forth, is tin metal, the rest being mild steel. That is why rust forms so easily on the cans when the protective thin coat of tin has been removed. Tinplating is the process by which thin sheets of mild steel, after tempering and cleaning with sulphuric acid, are dipped in a bath of molten tin over which is a flux of zinc chloride and through which the steel sheet passes before it is momentarily immersed in the liquid tin. In extracting the tinned plate from its bath the compartments are so arranged that it passes through hot palm oil. Recent advances in tinplating, such as the 'strip mill', have resulted in a continuous process of electrolytic deposition of tin metal on mild steel by which a thinner and more perfect coating of the metal is formed. Hence the introduc-

tion of electrolytic tinplate as a substitute for hot-dipped tinplate has been one of the most tin-saving developments of recent years. Some tinplate is also made by spraying the tin on steel.

The centre of tinplate manufacture in Britain is in South Wales, where more than 1,000,000 tons of steel and 16,000 tons of tin are used annually in this industry. In normal times a considerable amount of aluminium sheet was substituted for tinplate; and organic lacquers are also being used as a protective coating on thin steel sheets, instead of tin, for food containers.

The so-called 'silver paper' used for wrapping chocolates and formerly for cigarette packages is commonly a thin sheet of lead covered by a film of tin.

Approximately 40% of the total annual consumption of tin is in alloys, and 22% in solders. Formerly, soft solders contained 1 part of tin and 1 part of lead, but nowadays most solders contain 1 part of tin to 2 parts of lead, the principal uses of such solder being in the making of tin cans, automobile radiators, and electrical equipment. About 8% of the tin consumption is employed in the manufacture of the so-called babbitt bearing metals, which vary considerably in composition, many of them consisting of tin and lead in different proportions. The extensive application of ball and roller bearings has within recent years reduced the demands for bearing metals, especially for heavy machinery.

Bronzes consume 7% of the world's tin, much of modern bronze containing 88% copper, 10% tin and 2% zinc. Bell metal has 1 part of tin to 4 parts of copper, whereas in speculum metal the ratio is 1 part of tin to 2 parts of copper. Gun-metal has 1 part of tin to 9 parts of copper; and tough 'phosphor' bronze, containing 89% copper, 10% tin and 1% phosphorus, is used for pump plungers, valves and the

bushes of bearings. British copper coins are an alloy of 95% copper, 4% tin, and 1% zinc.

Britannia metal, used for spoons, forks and teapots, is essentially a tin-antimony alloy; and terne plate, a cheaper and duller form of material used mainly for roofing, is coated with an alloy of tin and lead instead of pure tin. Pewter, fashionable 100 years ago for drinking-vessels and other household utensils, contains usually 4 parts of tin to 1 part of lead.

It will come as a surprise to many readers to learn that hundreds of tons of tin are used annually in the making of silk stockings. In the form of tin chloride it is employed as a mordant for dyeing the natural and artificial silk, and in treating the material to make it rustle and to increase its weight.

Tin oxide is employed as an opacifying agent in the making of white glazes and enamels, thus presenting a white surface covering on the off-colour ware. There are several other uses for tin and its compounds, but satisfactory substitutes are rapidly being found for many of its applications, although it still remains an essential and highly important metal for many extensive industrial purposes.

### *Occurrence and Production*

The world's supply of tin metal is obtained virtually from one mineral only, cassiterite, the oxide of tin,  $\text{SnO}_2$ , but some of the metal is extracted also from its sulphide minerals, such as stannite, cylindrite and franckeite, which occur towards the south-eastern parts of the extensive Bolivian tinfield, in association with silver minerals.

Tin in metallic form does not occur in nature, and nowhere in the world have tin minerals been formed *in situ* except where the mineralization is genetically related to granite, or to rocks of the granite family, such as magmatic

quartz veins, pegmatites, aplites, rhyolites and quartz porphyries, or 'elvans', as these latter are termed in Cornwall. It is true that rich tin lodes have been worked successfully some distance from the granite contact, as in the 'killas' of Cornwall and metamorphosed sedimentaries in other countries, but even in these rocks the cassiterite is in veins or lodes composed of material derived from granitic magma.

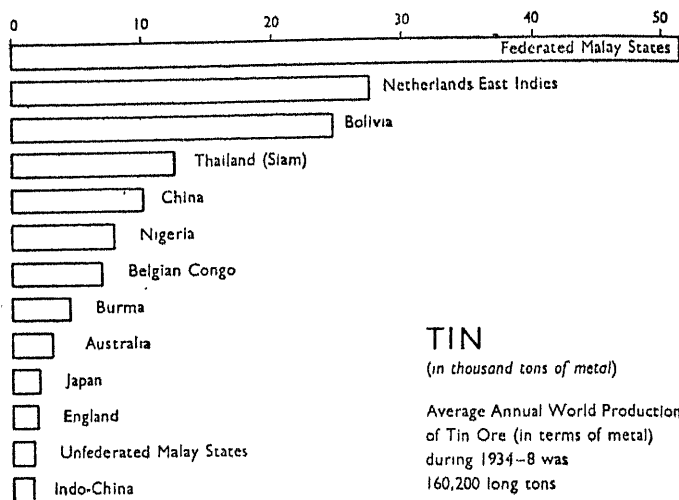


Fig. 24.

Furthermore, the cassiterite in alluvial and eluvial stanniferous deposits is derived from weathered mineralized areas intimately associated with these same types of igneous rocks. There is strong evidence that most tin was carried from acid igneous magma mainly in combination with fluorine and boron. By interaction with water vapour the metal was deposited as tin oxide, and the chemically active fluorine and boron thus released attacked some of the feldspars and biotite mica to form topaz and tourmaline,

two minerals which are of very common occurrence as intimate associates of cassiterite.

The world's chief tinfields can be resolved into a few groups, which can be conveniently termed 'metallogenic tin provinces' – that is, to parts of the earth's crust where tin mineralization, with respect to each group or province, was effected at the same geological period and under similar, or almost similar, conditions. The chief groups of tinfields with their average annual percentage of world production for the ten pre-war years, 1929–38, are as follows:

	Per cent.
(1) Malaya, Burma, Thailand (Siam) and Netherlands East Indies . . . . .	61.7
(2) Bolivia . . . . .	18.0
(3) China . . . . .	5.7
(4) Nigeria . . . . .	4.9
(5) Belgian Congo . . . . .	2.6
<hr/>	<hr/>
Total . . . . .	92.9
	<hr/>

By far the greatest production in all these, except Bolivia, was obtained from alluvial and eluvial (detrital) deposits which yielded about 70% of the world's tin. When it is considered that in Malaya one tin-dredger could recover in one day more cassiterite than would be accumulated naturally throughout the whole of the Malay Peninsula in a generation, it requires little imagination to realize what the result must be in the course of years. The history of tin-mining will inevitably repeat that of gold-mining. Within living memory the bulk of the world's gold was obtained from auriferous gravels, but in recent years most comes from lode-mining; and when the surface deposits of Malaya, China, Nigeria, and Belgian Congo are nearing exhaustion,

lode-mining will surely become the chief source of tin.

There is not a single tin mine in the whole of Canada and the U.S.A., and the very insignificant amounts of tin metal produced in those two countries are obtained as a by-product from mines, chiefly alluvial gold mines, worked for other metals. It is a striking anomaly that the countries which use most tin have practically no domestic sources of the metal, whereas those which yield most of the metal have little or no use for it. Even in this country the total production of Cornwall in normal times is only about 1% of that of the world, or a very small fraction of the amount consumed in the United Kingdom.

It is an interesting and significant fact that some of the Cornish lode mines, like Dolcoath which was closed some years ago, were started as copper mines. As the ore was followed in depth it changed more or less gradually from copper ore to copper-tin ore, then to tin-copper, and eventually into tin ore with only traces of copper. The copper-tin zone is usually not rich in the minerals of either copper or tin, and several mines were abandoned when that zone was reached. It is possible, and even probable, that some of these abandoned Cornish mines will be reopened in the future when the more easily worked alluvial and eluvial deposits in other countries are nearing exhaustion.

Before the Second World War the production of tin in the chief tinfields was under voluntary restriction to maintain an economic price for the metal, and some countries then produced more than their quota, whereas a few failed to reach their allocated tonnage.

In 1940 the total world production was about 238,000 long tons estimated as tin metal, of which Malaya yielded 36%; Netherlands East Indies, 18.7%; Bolivia, 16%; Thailand or Siam, 7.3%; Belgian Congo, 5.2%; China,

4·6%; Nigeria, 4·3%; Burma, 2·4%; Australia, 1·4%; and Cornwall, 0·8%. The countries occupied during the Second World War by Japan produced in pre-war days over 62% of the world's tin.

During the five years ended in 1952, the average annual production (in terms of metal) of the chief producing countries was: Malaya, 54,273 long tons; Bolivia, 33,623; Indonesia, 31,537; Belgian Congo, 13,777; Nigeria, 8,632; Siam (Thailand), 8,280; China, 4,600; Australia, 1,708; Burma, 1,435; Portugal, 1,073; Great Britain, 862 tons. For this quinquennial period, the average annual world production was 163,860 long tons.

The geographical distribution of the chief tinfields is shown in Fig. 27.

## TITANIUM

TITANIUM in combination with other elements is very abundant in nature, and, although the metal has been known for over a century and a half, it has proved less useful to man than almost any other metal or non-metal. It is true that the metal is difficult to extract from the minerals in which it occurs, but not more so than certain other metals, and the main reason for its few applications in industry is that it has no outstanding properties.

Its principal use, in the form of titanium oxide,  $\text{TiO}_2$ , is as a white paint pigment of remarkable opacity, which, owing to its cheapness, superior covering property, inertness and non-toxic qualities, is rapidly gaining favour over lithopone, white lead and zinc oxide pigments. It is estimated that titanium pigments have three times the opacity of white lead and twice that of zinc oxide, and they are now employed widely in enamel paints for interior and



exterior decorations. The bases of the two most common titanium paints consist respectively of 25% titanium oxide with 75% barium sulphate, and 30% titanium oxide with 70% calcium sulphate. Titanium oxide is used also in toilet preparations, linoleum, rubber, and other substances, but there are substitutes for it readily available.

In former years, ores of titanium were employed more than at present for making the alloys of ferrotitanium and ferrocenon-titanium, which, owing to their affinity for oxygen and nitrogen, act as deoxidizers and 'scavengers' in the manufacture of bessemer steel, once widely used for rails; but most steel rails are now made of open-hearth steel. Titanium carbide has beneficial effects in the manufacture of chromium steels, and an alloy of the carbides of titanium and molybdenum is coming into favour for extra-hard cutting tools.

Titanium, in the form of its minerals, ilmenite and rutile, as well as in the artificial compound titanium carbide, has long been utilized in arc lamp electrodes to improve the steadiness and intensity of the light, but arc lighting is now almost obsolete except in 'ultra-violet' lamps, the electrodes of which contain only 1.5% of titanium. It is interesting to note, however, that rutile as it occurs in nature is now much employed as a coating of rods used in electric welding for stabilizing the arc, and for ensuring the deposition of homogeneous and pure weld metals.

There is a limited but constant demand for titanium in the ceramic industry for producing cream-coloured and honey-yellow glazes and enamels; and as a colouring agent in glass. In dentistry it gives a natural colour to false teeth; and several titanium compounds, notably titanium potassium oxalate, are used extensively as dyes and mordants for cotton, wool, and silks, and for dyeing and staining leather. The chloride and sulphate of titanium are reputed to be the

most powerful acid-reducing agents known, and are excellent for bleaching textiles and for decoloring used paper and dyed fabrics. Titanous chloride is used in laundries for removing iron stains and for clearing coloured goods that have run in the wash.

Of particular importance in wartime is the application of titanium tetrachloride,  $\text{TiCl}_4$ , for producing smoke-screens to mask the movements of ships and troops. This liquid compound fumes rapidly, and by absorbing moisture from the atmosphere it forms dense white smoke clouds which are intensified in the presence of ammonia fumes. 'Sky-writing' by aeroplanes is another use of titanium tetrachloride.

Recently, large crystals of titanium oxide have been made artificially and sold as 'Titania' gems that are more brilliant than diamonds though not so hard and therefore not so resistant to wear. These gems are produced in colourless, blue and amber varieties.

### *Occurrence and Production*

Titanium minerals are among the most ubiquitous of all minerals, being present in most igneous, metamorphic and sedimentary rocks, but usually too sparsely disseminated for commercial extraction. Deposits of ilmenite of economic importance, however, are not uncommon, and are usually associated with basic igneous rocks of the gabbro family; they also occur as residual concentrations in beach sands.

The principal ore minerals of titanium are rutile,  $\text{TiO}_2$ ; ilmenite,  $\text{FeTiO}_3$ ; and the calcium titanosilicate, sphene, or titanite, as it is sometimes named. This latter mineral is worked on a moderate scale in the Kola Peninsula, U.S.S.R., but the world's chief supplies of titanium are from the ores of rutile and ilmenite.

These two minerals are formed in general under rela-

tively high-temperature conditions within igneous rocks. Rutile in workable amounts is much more restricted in its occurrence than ilmenite, and is found only in a few localities, the largest rutile deposit known being that of Roseland, Virginia, U.S.A., where it occurs in a felspathic pegmatite vein which also contains ilmenite. The second largest rutile deposit is probably that of Kragero in Southern Norway, where the rutile is present as disseminated grains in an albite aplite. Until fifty years ago Norway was the only country producing titanium minerals, all of it being rutile, at the rate of less than 100 tons a year. Beach sands containing rutile are now being worked near the New-South-Wales-Queensland border on the east coast of Australia.

Ilmenite does not occur in nature in large ore-bodies composed mainly of that mineral, but is present on a large scale in ilmenite-magnetite and ilmenite-hematite deposits associated with rocks like gabbro and anorthosite, from which the ore minerals have segregated during the crystallization of the magma. Huge masses of titaniferous iron ores, presumed to have originated in this way, occur in the Egersund district of Southern Norway and at Taberg in Sweden. The Norwegian ore was formerly shipped to England to be smelted for iron, but during the last two decades the deposit has been worked for the production of titanium white. It is curious that this black mineral should provide the finest white pigments used in industry.

Extensive deposits of titaniferous ores occur also in the basic rocks of the Adirondacks in the U.S.A. They are mined on a moderate scale for making ferrotitanium, but are too low-grade to compete successfully in normal times with other richer deposits. A titanium development of major proportions is under way in Quebec, where a very large deposit of ilmenite was discovered in 1946 at Allard

Lake, 22 miles north of Havre St Pierre on the Gulf of St Lawrence. The deposit is estimated to contain 150 million tons of ilmenite.

Black beach sands yield more than half of all ilmenite consumed, the most productive beach deposit in the world being in Travancore, on the south-west coast of India. Most of the ilmenite required for white pigment is obtained from these Travancore sands, which also supply important quantities of zircon and the cerium phosphate mineral, monazite. Although these sands have been worked for monazite for over three decades (see p. 137), it was not until 1924 that an effort was made to recover the ilmenite. In that year the production was 641 tons of ilmenite, but in 1938 it increased to a quarter of a million tons. In parts of Malaya, ilmenite is plentiful in the alluvial and eluvial tin deposits, and is recovered from the concentrates and heavy tailings by electromagnetic separation. Between 1936 and 1938 about 8,000 tons a year of ilmenite was recovered in this way in the Malay States, chiefly in Perak.

The total annual world production of ilmenite from 1936 to 1939 was in the neighbourhood of 266,000 long tons of which India yielded 68%; Norway, 25%; Malaya, 2.4%; Canada, 1.4%; Senegal, 1.1%; U.S.A., 1.1%; and all others about 1%. In 1952, U.S.A. produced 450,437 long tons of ilmenite; Canada, 238,046; India, 224,895; Norway, 116,402; Malaya, 21,698.

The total world production was well over a million tons.

In 1937 the production of rutile was approximately 2,500 tons of which Australia produced 45%; Brazil, 26%; U.S.A., 17%; Norway, 7%; French Cameroon, 4%; and others 1%. The geographical distribution of the chief ilmenite and rutile fields is shown in Fig. 28.

The production of rutile in 1952 was mainly from

Australia, 38,014 long tons; U.S.A., about 10,000; Cameroen (French), 289; India, 147; French West Africa, 25 tons. The total world production was about 50,000 tons.

## TUNGSTEN

THE most familiar use of tungsten metal is as filament in electric bulbs, but the tonnage so used is less than 2% of world production, whereas 95% of the total is consumed in the steel industry. The metal was first discovered 155 years ago, but the unrivalled qualities of tungsten filament were not realized until the present century; and to-day, at an average cost to the manufacturer of about a penny per filament, light-bulbs confer an immeasurable boon in the home, in industrial plants and in all places where the artificial-light source is electricity. Less than 2 tons of tungsten metal are required to supply filaments for 100 million electric bulbs, and although in the U.S.A. alone more than 1,000 million tungsten lamps were sold in 1940, it is estimated that the total annual world consumption of the metal for light filaments is little more than 100 tons. Tungsten filament is four and a half times as efficient as carbon filament, and its use has thus resulted, according to reliable authority, in the annual saving of electricity and electric bulbs to the extent of many hundreds of millions of pounds. Possibly no other metal during the last three decades, used in equal amount for any purpose, has been of greater service to man than tungsten in the form of filament. The metal is employed also in wireless valves, as targets or cathodes for X-ray tubes, as contact points in electrical apparatus; and on account of its high melting point, which is the highest ( $3,370^{\circ}\text{C.}$ ) of any metal, and over  $1,500^{\circ}\text{C.}$  higher than that of platinum, it is now commonly used in crucibles

and sparking plugs. The remarkable ductility and high tensile strength of the metal enable it to be drawn into very thin wire or filament, one five-thousandth of an inch in diameter.

Its principal use in the steel industry is in the manufacture of high-speed tool steels, which can cut ordinary steel almost as easily as a knife cuts cheese. These tools retain their hardness up to red heat, are self-tempering and are indispensable in modern workshops, particularly in munition plants, where the best and fastest cutting tools are essential for the rapid production of tanks, aeroplanes and other war weapons. A cutting machine using tungsten steel can be run at five times the speed possible with carbon steel and make heavier cuts, so that jobs now take minutes where with carbon steel they took hours.

One of the commonest tungsten steels contains, in addition to steel, about 18% tungsten, 4% chromium and 1% vanadium; but other tungsten alloys, containing also molybdenum and cobalt, are now extensively used. High-speed tungsten steel is employed also for valves and valve-seats for internal-combustion engines, and as dies for wire-drawing. Small amounts of tungsten are used in a great variety of complex alloy steels for stainless steels, motor-car springs, grinding tools, knife and razor blades, drilling tools, files, hack-saws, crushing stamps, electrical resistance wires, and so forth. Tungsten alloy steels are employed in armour-piercing shells, in the manufacture of armour plate, and for gun breeches. It is estimated that in the U.S.A., 90% of the tungsten consumed is used in ferrous alloys.

An increasing amount of tungsten is being used in non-ferrous alloys, especially those of the stellite group, which contain about 60% cobalt, 30% chromium and 10% tungsten. These alloys are widely employed nowadays in

cutting and machine tools and for hard facings. Stellite bits are often used instead of diamond-set crowns for boring through rocks.

A very recent and important development in the use of tungsten is for making tungsten carbide in various forms as a super-hard cutting tool for machine work. The finely ground carbide is, with the exception of diamond and boron carbide, the hardest known cutting agent, and its introduction is considered to be the most important development in metal cutting since high-speed tools were invented. 'These carbide tools are stated to stand up under the same speed as high-speed tool steel, but last 25 to 100 times as long between sharpenings, and in addition can be used for cutting glass, porcelain, and manganese steel which no ordinary tool can touch.'

Tungsten compounds are utilized as pigments in paint and ceramic ware, and sodium tungstate serves for fire-proofing curtains and draperies.

### *Occurrence and Production*

The most important sources of tungsten are the minerals, wolfram,  $(\text{FeMn})\text{WO}_4$ , and scheelite,  $\text{CaWO}_4$ , but in a few parts of the U.S.A. the mineral ferberite,  $\text{FeWO}_4$ , and to a lesser extent the mineral hubnerite,  $\text{MnWO}_4$ , are valuable sources of the metal.

Wolfram is a frequent associate of cassiterite in quartz and pegmatite veins traversing granitic rocks and metamorphosed sedimentaries invaded by such rocks. Usually it is more common in the veins cutting through the metamorphosed sedimentaries, like phyllites and schists, than in those traversing granite. Scheelite is typically found in contact metamorphic deposits, especially where limestones have been mineralized by tungsten-bearing solutions derived from granitic magmas, the calcium in the limestone com-

bining with the tungsten to form calcium tungstate. Ferberite is restricted in its occurrence mainly to Boulder County, Colorado, where it occurs in narrow, brecciated quartz veins traversing granite; and hubnerite has a somewhat similar mode of occurrence.

Wolfram is less stable than cassiterite, and on account of its good cleavage in one direction it breaks into thin flakes, thus exposing additional surfaces to natural weathering processes. In tropical countries, true alluvial deposits do not carry workable amounts of wolfram, although loose detrital deposits on hill slopes, that can be worked by hydraulic methods, yield a good deal of the mineral. This is the case in parts of China and in the Tavoy and Mergui districts of Southern Burma, where surface deposits are worked extensively

Following the discovery of wolfram in China in 1914, that country four years later became the leading producer of the mineral, with an output of about 10,000 long tons, obtained mainly from surface deposits on hill and mountain slopes in the province of Kiangsi, and to a lesser extent from Kwantung. Wolfram veins are also worked in these parts.

For a long period of years prior to 1918, Burma was the chief source of wolfram and, until the Japanese occupation, Mawchi Mines in Upper Burma was the largest wolfram-producing mine in the world, with an average monthly output of over 400 tons of tin-tungsten concentrates, containing approximately equal amounts of wolfram and cassiterite. The Tavoy and Mergui districts in Lower Burma were the chief sources before 1918.

Most of the world's scheelite is obtained from California and Nevada, where the mineral occurs mainly in veins. At Atolia in California, scheelite and gold are present in quartz veins, which have long been worked on a large scale; and in Nevada the mineral is chiefly in contact-



metamorphic rocks.

In Bolivia, wolfram and some scheelite are found throughout the tin belt, but in general are not intimately associated with cassiterite. The principal tungsten mines are in the Department of La Paz, where the quartz veins traverse metamorphosed sedimentaries almost at right angles to the

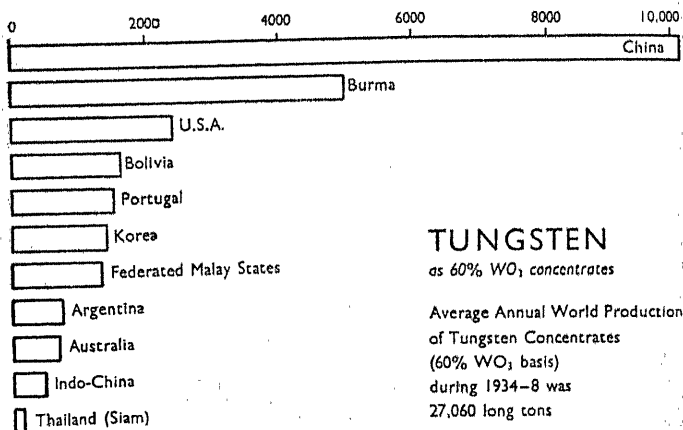


Fig. 25.

granite contact. Wolfram predominates over scheelite, and occasionally ferberite and hubnerite are present.

The largest wolfram mine in Europe is Panasqueira, in Beira Baixa, Portugal, where numerous lenticular quartz veins dipping at a low angle of less than 10 degrees are worked extensively. The narrow veins occupy joint-planes in phyllites, and in places carry tin and tungsten minerals with, in parts, much arsenopyrite and pyrite. In 1940 shipments from Portugal amounted to nearly 4,800 tons, of which more than half was obtained from Panasqueira Mine.

Wolfram is also worked on a small scale in parts of Cornwall, mainly as a by-product in tin mines, but at

Castle-an-Dinas mine the small output is exclusively wolfram. In 1939 and 1940 the total Cornish production for each year was 250 long tons of wolfram, which represented about 2% of the United Kingdom's consumption of tungsten. Other parts of Cornwall and Devon have been worked for this mineral.

World production of tungsten minerals in 1938 exceeded 36,000 long tons, containing an average of 60% of tungstic oxide,  $WO_3$ . Of this tonnage China produced 13,000; Burma, 11,200; the U.S.A., 2,700; Portugal, 2,800; and Bolivia, 2,500 tons. During 1940-4 intensive search for wolfram was made in Portugal and Spain, where exceptionally high prices were paid for the mineral. The geographical distribution of the chief tungsten fields is shown in Fig. 30.

World production of tungsten concentrates (in terms of 60% tungstic oxide) increased from about 36,000 tons in 1938 to over 56,000 tons in 1943.

During the five years ended in 1952, the average annual production of the chief producing countries (in terms of 60%  $WO_3$ ) was: China, 13,600 long tons; U.S.S.R., 6,400; U.S.A., 4,554; Portugal, 3,489; Bolivia, 2,739; Korea, 2,700; Australia, 1,522; Spain, 1,489; Burma, 1,260. For this quinquennial period, the average annual world production was 42,600 long tons.

## URANIUM: RADIUM, PLUTONIUM

PUBLIC interest in uranium minerals was first aroused following the discovery of radium in 1898 by Professor and Madame Curie in the uraninite (pitchblende) deposits of Joachimstal in Czechoslovakia. Interest was intensified a million-fold when the public learnt that uranium was the

source of energy that caused untold destruction when the atom bomb was dropped on Hiroshima on 6 August 1945, and on Nagasaki three days later. Realization of the catastrophe to civilization that would lie ahead in the event of atomic warfare, coupled with belief in the vast possibilities in the future peaceful use of atomic energy in industry, have maintained the subject of uranium minerals right in the forefront of public and of scientific interest.

Until the outbreak of the Second World War uranium minerals were worked chiefly for their radium content. Uranium is also used, in the form of salts, to impart to glass, porcelain and pottery glazes tints of yellow, orange, golden and ruby, and to make iridescent glass. The salts are also employed as mordants in dyeing and calico-printing, and small quantities are used in photography and in analytical chemistry. The attempts to make use of uranium-bearing alloys have not been very successful.

The increasing demand for radium in the years immediately before the war (in 1938 the annual demand was about 100 grams of radium, equivalent to about 450 tons of uranium oxide) was creating a surplus of uranium by-products, and the residues containing uranium after the extraction of radium were not all saleable and were dumped as waste outside the refineries. Uranium has now become pre-eminently important whilst radium has become of lesser importance because, during uranium fission in the atomic pile, a great array of fission products become available. These supply a large range of types and of intensities of radiation and thus are convenient substitutes for radium and for its highly active gaseous decomposition product, radon.

Uranium metal was first isolated a century ago, but until 1940 it was so little known that even some of its physical properties, such as its melting point, had not been deter-

mined precisely. Its most remarkable property, and that of its associate, radium, is radioactivity. It was the discovery of this property that gave the first impulse to what is now known as atomic physics. During the stages of its natural disintegration, uranium produces a series of elements including helium, radium, actinium and lead. Thus the dream of the alchemists – the transmutation of the elements – had been going on unnoticed in the laboratory of nature for millions of years! And it was the discovery of 'fission', or bursting of uranium atoms in 1939 that gave the first indication of the possibility of releasing atomic energy on a large scale. The first demonstration of such release was on 16 July 1945, when the U.S.A. Army carried out the test at the atomic-bomb range, Los Alamos, New Mexico.

Uranium is known to have three different atomic weights, namely, 234, 235 and 238. U 238 is by far the most abundant variety, U 235 which occurs with it being in the ratio of 1 part in 140 parts of U 238. These two varieties are isotopes and cannot be separated from one another by any chemical means. No physical method of separation on a practical scale was known until it was solved by the atomic bomb project in the U.S.A., although it had first been isolated in the laboratory in 1940. The metal, plutonium, is created through the fission of U 235. The transmutation of U 238 into plutonium is stated to increase more than a hundred-fold the source available for atomic power. Plutonium, which does not exist naturally, is chemically different from uranium and thus can be separated from uranium by chemical means. It was first made in the U.S.A. in 1942 and at Harwell in Berkshire in February 1949.

When uranium and heavy water are brought together in certain proportions and in sufficient quantity, a 'chain'

reaction is set up and large quantities of energy are released from the uranium in a controlled and non-explosive manner. One system of producing atomic energy consists of large blocks of pure graphite into which cylinders of uranium metal are inserted through cylindrical pockets. This installation is known as the atomic pile, or primary reactor, and it is surrounded by very thick concrete walls for protection against neutron and gamma radiation, control of the pile being from a distance.

### *Occurrence*

Dozens of minerals contain uranium, but the most important of the uranium minerals is uraninite, the colloform variety of which is known as 'pitchblende', on account of its velvet-black or pitch-like lustre. It is an extremely complex mineral: a uranate of uranyl, lead, usually thorium (or zirconium), often with the metals of the lanthanum and yttrium groups and containing the gases nitrogen, helium and argon in varying amounts up to 2.6%, and other elements may be present. Although the first discovery of radium was in pitchblende, another mineral, carnotite, a yellow hydrous vanadate present as powdery aggregates in the Jurassic sandstones of Colorado and Utah, later became a more important source of uranium.

Uraninite, or pitchblende, occurs in pegmatites, in granites, and in certain metalliferous veins containing the ores of tin, copper, or lead and silver, where the uranium-bearing mineral was deposited by mineralizing solutions. One of the most important uranium deposits of the world is that of Chinkolobwe in the Belgian Congo, discovered in 1913 near the copper mine Kambove in the Katanga District. The pitchblende is accompanied by various spectacularly coloured oxidized uranium minerals, such as the

green mineral torbernite; the lemon- to sulphur-yellow autunite; the reddish-brown to deep yellow curite (named after the discoverer of radium); gummite and others which occur as disseminations and veins in dolomite. It is generally accepted that these deposits are genetically related to the famous extensive copper ores of Katanga in Belgian Congo and that they were formed by ascending magmatic solutions. They proved so rich that it was no longer possible for the carnotite deposits of Colorado and Utah to withstand competition. Before 1938 the uranium ores of Belgian Congo, containing about 40% of uranium oxide, were refined at Oolen in Belgium. Most of the radium stored in that country was sent to England at an early stage in the Second World War. For many years Belgium had a virtual monopoly in radium, but the discovery in 1930 of the now famous deposits at the Great Bear Lake in the North-West Territories of Canada heralded the end of that domination of the radium and uranium market.

These Canadian deposits are well within the Arctic Circle, and their discovery and development form a thrilling chapter in mining history. Canadians can well feel proud of the enterprise of their geologists and mining engineers which eventually resulted in reducing the price of radium by 62% between 1933 and 1937. The story is unfortunately outside the scope of this small book.

The Great Bear Lake deposits are in shear zones traversing metamorphosed lavas and sediments near their contact with intrusive granite. The pitchblende is associated with native silver and nickel-cobalt arsenides, formed as the result of ascending hydrothermal mineralizing solutions from an igneous source. The ores are exceptionally rich, and the concentrates are transported by air to rail-head, and thence to the refinery at Port Hope in Ontario. The Eldorado mine, Great Bear Lake, and the refinery at

Port Hope, were expropriated for war purposes in February 1943, and a Crown Company was established to carry on the production of uranium and radium. Eldorado mine was the chief source of the uranium used in the manufacture of the atomic bombs that were dropped on Japan in August 1945.

The once-famous mines at Joachimstal in Czechoslovakia still supply quantities of uranium and there has been considerable renewed mining activity there during 1946 to 1950. It is interesting to note that at the beginning of the present century uranium minerals, from which small quantities of radium were extracted, were mined in Cornwall and Devon and also in Portugal. Potentially important deposits of uranium minerals are known also in Madagascar; at Mount Painter, South Australia; and in Russian Turkestan where there are deposits of tyuyamunite (hydrated calcium uranyl vanadate) in the south-eastern part of Fergana.

In 1941 it was estimated that about 75% of the world's known reserves of uranium were in the hands of the United Nations, those of the Great Bear Lake in Canada, the Katanga deposits in Belgian Congo, and the carnotite deposits of Colorado and Utah forming about 70% of the world's proved resources. It must be realized, however, that when uranium minerals were mined solely for radium, only the richer deposits could be worked commercially. The position is now entirely changed, for uranium has become a metal of the highest possible strategic importance. Moreover, when success attends the tremendous efforts now being made to harness atomic power to peaceful industries, uranium may become even more valuable than gold, and low-grade deposits of uranium minerals, formerly considered too poor to work, will become important sources of the metal.

Most rocks are radioactive to some extent, but some,

such as certain pegmatites and granites, are much more so than other types of rocks. Pegmatites and granites are of widespread occurrence in many countries and the improved methods for testing rocks for their radioactivity (for example, with the Geiger Counter field unit) are contributing to discoveries of previously unknown occurrences of radioactive minerals in many countries. The Professor of Ore-dressing at the Institute of Non-Ferrous Metals and Gold, Moscow, stated in 1946 that new sources of radioactive minerals had been found in the Ucta region in natural water and that the radioactive substances were being extracted from it.

Australia has extensive deposits of uranium minerals at Radium Hill in South Australia and at Rum Jungle in the Northern Territory.

One of the most important occurrences of uranium in the world is that of the Witwatersrand Goldfield, South Africa. The uranium is recovered from the cyanide slime residues in the mine dumps, and already the annual production is approaching the estimated revenue from this source of £30 millions.

### *Production*

Before 1923 the U.S.A. carnotite deposits were the main source of uranium and radium; then came the discovery of the rich Belgian Congo uraninite deposits which, by 1929, had surpassed the American production; and, following the discovery in 1930 of the still richer uraninite (pitchblende) deposits of the Great Bear Lake, Canada became the world's chief source of radium. In 1938 Canada produced 75 grams (about  $2\frac{1}{2}$  ounces) of radium and 358 tons of uranium, but in the pre-war years, when the world production of uranium was about 1,000 tons a year, Belgian Congo was the chief source of that metal, but not of radium.



Since 1943 statistics concerning the production of uranium in different countries have been withheld from publication, but it is known that Belgian Congo reported exports of 176,500 cwt. of uranium ore in 1944 and 196,190 cwt. in 1945. The control of uranium metal and uranium ores is a subject that has long been discussed as a major international problem.

## VANADIUM

ALTHOUGH the metal vanadium used alone has practically no industrial applications, about 95% of the world's supply is consumed in the manufacture of special alloy steels, such as high-speed tool steels, the remaining 5% being utilized in various chemicals. In the form of ferro-vanadium it is employed in steel manufacture, the vanadium acting as a scavenger for oxygen, besides producing a valuable fine-grained product of remarkable toughness and resistance to torsion and high temperature. Usually, less than 1% of vanadium suffices to impart its beneficial effects to steel, rendering it well suitable for uses involving strains. For forging and spring steels, only 0.2% vanadium is required, while high-speed tool steels may contain 1% of the metal. Vanadium steels have the reputation for being fool-proof in their metallurgical preparation, and are used extensively in locomotive and automobile forgings, transmission shafts, gears, axles, springs and so forth, for they possess splendid forging and machining properties and are easily welded. They are also used as constructional steels and pressure vessels, for making rock-crushers, dredges, air-compression and other heavy-duty machinery; and also to some extent for armour plate, gun parts and armour-piercing shells.

Within recent years molybdenum-vanadium steels, with and without chromium, have added to cast iron great strength with low hardness and ease of machining; and for some special purposes a small percentage of vanadium is added to brass and bronze.

Minor amounts of vanadium salts are employed in printing fabrics, in dyeing processes and in paints and medicines. The yellow pigment, vanadium bronze, is metavanadic acid.

A comparatively new and important development is the use of vanadium pentoxide,  $V_2O_5$ , as a substitute for the much more expensive platinum as a catalyst in the manufacture of sulphuric acid by the contact process. Probably half the world production of sulphuric acid by this process is now made with vanadium pentoxide as catalyst, and it appears probable that eventually it will replace platinum altogether for this purpose.

### *Occurrence and Production*

Vanadium in combination with other elements is widely distributed in igneous and sedimentary rocks, but only in small quantities, although it may, as the result of the decomposition of the minerals containing it, become more concentrated in iron-rich soils and bauxitic clays. It is commonly present also in organic remains and in the ashes of bitumens, asphalts, coals and petroleum in varying amounts, but only rarely to the extent of 12%. It is an interesting fact that more than 20 tons of vanadium pentoxide is recovered annually from the soot that collects in the boilers and stacks of ships burning Venezuelan and Mexican fuel oil; and it is probable that Italy recovers about 50 tons a year from soot and ashes taken from oil-burning vessels and industrial plants. Certain Peruvian asphalts yield more than 30% of vanadic oxide from their

ash; and at Minasragra in Peru, the world's chief source of vanadium, the ore occurs in black carbonaceous rocks resembling coal or asphalt and containing 10% to 13% vanadium.

The most important vanadium minerals are patronite,  $VS_4$ ; descloizite, a complex lead-vanadium mineral; roscoelite, a green mica containing 2% vanadium; and carnotite, a canary-yellow, powdery mineral which is one of the sources of radium; and lastly vanadinite, a lead-vanadium mineral of secondary origin found in the oxidation zone of certain lead-zinc deposits. These minerals vary in their mode of occurrence, vanadium ores being of magmatic, secondary and organic origin. Those of Norway and the Urals are of magmatic origin; those in the oxidized portions of the lead-zinc deposits of Broken Hill in Northern Rhodesia, and near Otavi in South-West Africa, are of secondary origin; and so probably are the carnotite deposits forming the cementing material of Jurassic sandstones in Colorado and Utah in the U.S.A. The vanadium compounds present in coals, asphalts and petroleum are of organic origin.

World production of vanadium in 1939 was approximately 3,000 tons, of which Peru yielded 34%; U.S.A., 30%; South-West Africa, 17%; Northern Rhodesia, 13%; Mexico, 5%. The geographical distribution of the chief vanadium fields is shown in Fig. 30.

In 1947 U.S.A. produced, in terms of the metal in long tons, 946 tons; Peru, 428; South-West Africa, 222; Northern Rhodesia, 56 tons. In 1948 Northern Rhodesia produced 304 tons of vanadium, in terms of  $V_2O_5$  content. Since 1947 figures of U.S.A. production have not been available. In 1952, South-West Africa produced 614 long tons of vanadium ore (in terms of metal); Peru, about 650; and Northern Rhodesia, 43 tons.

## VERMICULITE

A quarter of a century ago vermiculite was merely one of the commercially useless minerals which geologists patiently studied for its scientific interest only. Its recent industrial application serves as one of the many examples of the value of researches initially undertaken for purely scientific purposes, but which later have resulted in adding to the everyday amenities in apartment houses, cinemas, theatres, and in engine-testing buildings.

The name 'vermiculite' is applied to those biotite micas which have undergone alteration by hydrothermal solutions, so that when heated they swell to ten times and more of their original volume by exfoliation and with a twisting worm-like movement. The original mineral is of dark yellowish-brown colour, but after expansion on heating it assumes a pale yellow tint and weighs less than 10 lb. per cubic foot.

More than half the total consumption of vermiculite is for insulating interior walls of buildings. It is sold under various trade names such as 'mineral cork', 'mica pellets', 'absorbite', 'Exflor' etc. Mixed with Portland cement it can be 'poured in place or pre-cast into lightweight, fire-proof slabs or partition walls, floors and roofs'. Buildings where sound-deadening is of importance, as for aeroplane-engine testing, are increasingly constructed of vermiculite concrete; and plasters made of gypsum and vermiculite are rapidly gaining favour for acoustical, insulating, and fire-proof purposes. The mineral is effectively employed also in refrigerators and for pipe and boiler coverings.

Finely ground vermiculite can be substituted for graphite in oil-less lubricants for bronze-bearings, and is claimed to

have beneficial results when introduced into worn internal combustion engines by diminishing piston-slap.

### *Occurrence and Production.*

The largest and most productive vermiculite deposits are in Montana, U.S.A., where the mineral occurs in association with basic igneous rocks as a single huge dyke-like mass, about 1,000 feet long and 100 feet wide, and proved to persist to a depth of at least 100 feet. It occurs in other parts of the U.S.A., and in Palabora district of Transvaal; in Tanganyika; and in the Urals, U.S.S.R.

The U.S.A. produced 60,000 tons in 1936, 77,000 tons in 1946 and approximately 117,300 tons in 1947. A considerable tonnage of the U.S.A. production is marketed under trade names such as 'Zonolite' and 'Zonotherm'. There was an increase in the production of South Africa from 4,900 tons in 1946 to 14,085 tons in 1947, of which the Union of South Africa yielded 9,715 tons. In 1952, U.S.A. produced 187,500 long tons; South Africa, 32,641; Southern Rhodesia, about 500; Australia, 62 tons.

## ZINC

A HUNDRED years ago zinc metal had very few uses, virtually only for making small quantities of brass; and the chief zinc mineral, which is frequently associated with the chief lead mineral, was considered a nuisance in lead-mines and dumped as worthless material. In fact, the name given to that zinc mineral was sphalerite, or blende, meaning 'deceptive' in allusion to its worthlessness combined with its resemblance to the useful mineral, galena, the chief source of lead and silver.

Late in the nineteenth century the rapidly growing

electrical industry needed large amounts of brass, not particularly for the electrical properties of that copper-zinc alloy, but because it could be formed easily into intricate patterns, had suitable hardness, a pleasing appearance and could be kept polished. At about this time it was found also that zinc oxide produced a whiter paint pigment than lead oxide, and that the metal could be rolled into sheets to form articles that resisted corrosion.

The most outstanding discovery of the use of the metal, however, was that a thin coating of it protected iron sheets over a long period from rusting, and its most familiar and important application since that discovery has been in the manufacture of galvanized corrugated iron for roofs and sides of cheap buildings throughout the world. In the early days of galvanized sheeting, the zinc was deposited on iron by means of an electric current - that is, by the process of 'galvanizing' - but this was soon supplanted by the present method of dipping the carefully cleaned iron in a bath of molten zinc, or, as is less usually practised, by exposing the iron to zinc vapour. The corrugation of the sheets increases their stiffness and allows them to overlap along the edges to be water-tight, and their lightness and ease of fixing are immensely advantageous. Within recent years steel wire has been galvanized electrolytically, and millions of miles of galvanized wire netting, and hundreds of millions of miles of galvanized wire fencing, are in use; also bolts, nuts, screws, nails, chains, pipes, tubes, and numerous other forms of iron are prevented from rusting by a thin coat of zinc.

Sheet zinc, or rolled zinc, is used in collapsible tubes and for glass-jar tops; as the negative pole of electric batteries, as the cylinder container of dry batteries as utilized in the pocket electric torch and for electric bells; and during the last twelve years there has been rapid increase in the con-

sumption of the metal for zinc die castings now used extensively for radiator grilles, hub caps, carburettors and so forth in the automobile industry.

Zinc dust is utilized in the chemical industries as a reducing agent, and in dye-making. The oxide of the metal is widely used as a paint pigment, and large amounts of zinc sulphide are consumed annually for making the barium-zinc pigment known as lithopone (see p. 43).

Zinc is a constituent of many alloys besides brass, such as German silver, white metal, and the so-called manganese bronze used in propeller screws. Zinc salts are used in medicine, in dental preparations and various chemicals such as zinc sulphate ('white vitriol'); as a disinfectant and mordant in dyeing processes, and zinc chloride as a wood preservative. There are many other minor applications of zinc in some form or other. Owing to the shortage of cadmium, zinc electroplating is now of increased importance.

### *Occurrence and Production*

The chief source of zinc is the mineral, sphalerite, or zinc blende,  $\text{ZnS}$ , but two other minerals, smithsonite ('calamine'),  $\text{ZnCO}_3$ , and hemimorphite,  $2\text{ZnO} \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$ , both of which in hot and dry climates frequently occur in large quantities in the upper and oxidized parts of zinc deposits, contribute important quantities of the metal.

These three minerals usually occur in association with lead minerals, and there is, in fact, only one important zinc field known where the ore is worked only for zinc - namely, that of Franklin Furnace, New Jersey, in the U.S.A., where there is a remarkable assemblage of zinc minerals not known in economic quantities in any other mining field. At Franklin Furnace the red oxide of zinc, zincite; the generally greenish-yellow zinc silicate, willemite; and the

black complex zinc-bearing oxide, franklinite, are the sources of the metal. The origin of these New Jersey deposits is controversial; possibly the original zinc sulphides were later oxidized to form the zinc minerals as they now occur.

The great majority of zinc deposits, however, contain the lead mineral, galena, and both the lead and zinc minerals

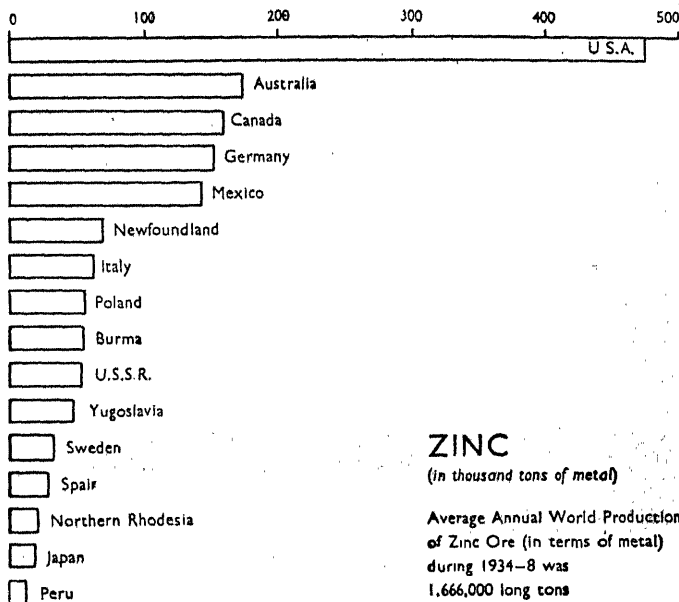


Fig. 26.

are mined together. Many of the most productive zinc mines are also the most productive lead mines, such as the Sullivan Mine in British Columbia; Canada (the largest lead-zinc mine in the world); the famous mines of Broken Hill, New South Wales; the Bawdwin Mines in Upper Burma; the mines in the Tri-State (chiefly Oklahoma)



region of the U.S.A., which produce nearly 12% of the world's supply of zinc, and many others.

Most of the zinc deposits, like those of lead (see p. 111), are found in veins or lodes, or as replacements and disseminations in various sedimentary rocks, but especially in limestones and dolomites. In general, the zinc and lead minerals were deposited by hot ascending mineralizing solutions, and in many cases, but not in all, the temperature and pressure conditions during mineralization were moderate in degree. Some of the largest ore-bodies, however, were formed under high temperatures and pressures — for example, at Sullivan, Broken Hill, and the Bawdwin Mines.

The Broken Hill ore-bodies of New South Wales, rich in zinc blende and argentiferous galena, are located in a shear zone traversing sedimentary, igneous and metamorphic rocks. The ores range in zinc content from 9% to 14%; in lead from 12% to 16%; and in silver from 3 to 12 ounces per ton.

At Sullivan in British Columbia, the ore-bodies contain zinc blende and galena as replacements of pre-Cambrian quartzites, the ore carrying about 13% and 11% lead.

At the Bawdwin Mines, Burma, the ore-bodies are in a zone of crushed and faulted rocks in rhyolites and rhyolite tuffs, and average about 24% lead and 15% zinc, thus being among the richest lead-zinc deposits in the world.

In the Tri-State field of the U.S.A., which includes parts of Missouri, Oklahoma and Kansas, the lead-zinc deposits occur in 'runs and circles' in broken cherty limestone near the surface, and in sheets or beds along particular strata. The modern theory of their origin is that they were formed by the replacement of limestone by hot ascending mineralizing solutions emanating from igneous sources below.

Great Britain produced, during the first decade of the

nineteenth century, more than a third of the world production of zinc from lead-zinc mines in Derbyshire, north of England, and parts of Wales. Most of these mines have remained derelict for many years, the last important zinc-producing mine to be closed in this county being Mill Close Mine in Derbyshire, which ceased mining operations some ten years ago.

It is now generally accepted that almost all, if not all, zinc and lead deposits owe their origin to hot mineralizing solutions emanating from below and not, as was formerly believed, to secretion and concentration from rocks containing small percentages of zinc and lead, by percolating descending waters. In the great majority of cases the actual igneous source of the mineralizing solutions has been discovered, whereas in most of the others the source, though distant, is suspected on strong geological evidence.

For the quinquennial period 1934-8, the average annual world production of zinc metal was 1,666,000 long tons, of which the U.S.A. yielded 29%. The production of other countries is shown in the accompanying diagram, Fig. 26. The geographical distribution of the chief zinc fields is shown in Fig. 27.

During the five years ended in 1952, the average annual production (in terms of metal) of the chief producing countries was: U.S.A., 569,423 long tons; Canada, 283,360; U.S.S.R., 214,000; Mexico, 194,558; Australia, 194,144; Poland, 105,000; Peru, 86,755; Italy, 84,900; Belgian Congo, 72,197; Spain, 63,434; Germany, 62,560; Japan, 55,460. For this quinquennial period, the average annual world production was 570,000 long tons.

## ZIRCONIUM

ONE of the earliest incandescent gas mantles (Welsbach) was treated with zirconium nitrate derived from zirconium minerals, and this was one of the first uses for these minerals, but it was soon found that thorium nitrate proved more effective for gas mantles. Later, zirconia was utilized to a limited extent as a glower in the Nernst lamp.

During the last two decades the consumption of zirconium and its compounds has increased considerably, owing to the remarkable refractory properties of the oxide of zirconium, zirconia, which is now extensively employed for making crucibles, muffle furnaces, firebricks and other materials which are subjected to exceptionally high temperatures and rapid fluctuations of temperature. Zirconia crucibles can withstand a temperature of  $2,300^{\circ}\text{C}.$ , and are employed in melting platinum at a temperature of  $1,755^{\circ}\text{C}.$  Zirconium refractories have also a very low coefficient of expansion, freedom from corrosion and cracking, and high mechanical strength. Moreover, electrical porcelains containing zirconium, such as are used for the best sparking-plugs, have a very high dielectric strength and are effective under most rigorous conditions. Special refractories for refining precious metals, and for the roofs of electric furnaces, are frequently made of zirconia; in fact, zirconia is one of the best refractories known for these purposes. It also finds applications as a white opacifier in the enamel industry, in the manufacture of paints and lacquers, as an abrasive and polishing powder, and as an insulator for heat and electricity.

The metal, zirconium, has recently been employed in wireless valves and electrodes, and a new use is in flashlight

powders and ammunition primers. Several hard zirconium alloys, in which the metal accompanies aluminium, manganese, silicon and others, are now in common use. Cooperite, a nickel-zirconium alloy, is acid-resistant, non-rusting, very hard and makes an efficient high-speed cutting tool. Ferrozirconium, an alloy of iron and zirconium, is used in the steel industry as a scavenger, the zirconium uniting readily with oxygen and nitrogen. The metal is utilized also in making zirconium steel, which is stated to make a superior light armour plate, and projectiles.

The mineral, zircon,  $\text{ZrSiO}_4$ , when transparent serves as a gem-stone. It may be colourless, but more often is brownish or red-orange in colour, and is then known as hyacinth, or jacinth. By heat treatment some of the colours can be changed to blue. The colourless, yellowish and smoky varieties are called 'jargon', for while they resemble diamond they, like certain phrases, have little value.

### *Occurrence and Production*

Almost all the zirconium of commerce comes from two minerals, zircon,  $\text{ZrSiO}_4$ , and baddeleyite,  $\text{ZrO}_2$ , which is sometimes known as brazilite.

Zircon is a minor constituent of most types of igneous rocks, but especially of granites, pegmatites and of nepheline syenites, where it may occur in abundance. It is usually one of the first minerals to crystallize out from the magma. It is, however, from the alluvial deposits derived from these rocks that the mineral is won. The zircon, being very resistant to weathering agencies and heavier than most of the associated minerals, becomes concentrated in parts of the alluvium with other heavy minerals such as monazite, ilmenite, rutile and others.

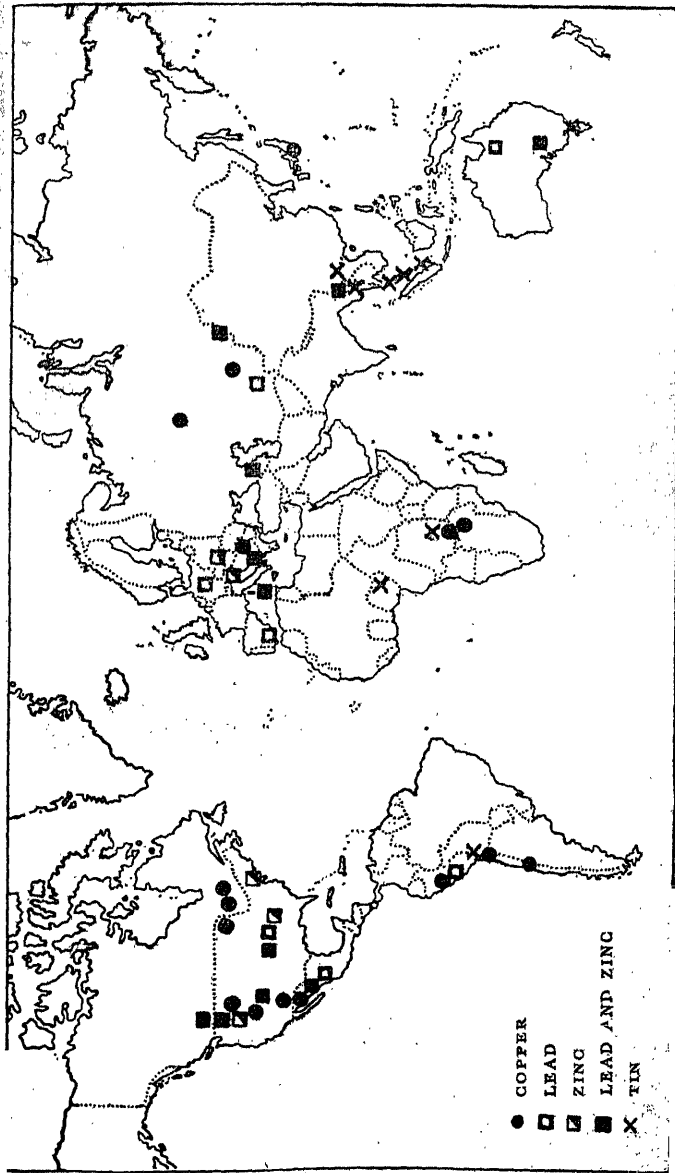
The much rarer mineral, baddeleyite, occurs in pegmatites which also yield alluvial (placer) deposits from

which the mineral is recovered. Baddeleyite was first discovered about fifty years ago in the gem gravels of Ceylon, but occurs in economic quantities only in Brazil, where it is present in water-worn pebbles and boulders in stream gravels.

The most productive source of zirconium minerals is the naturally concentrated zircon-rutile-ilmenite black sands at Byron Bay, in New South Wales, where, in 1937, the production reached 5,251 long tons of zircon. Brazil is the second largest producer, chiefly as baddeleyite, with 2,317 tons in 1937; and the Travancore monazite sands in south-west India yielded in that year 1,329 tons of zircon. Small outputs are obtained also from French West Africa, Madagascar, Florida and Norway.

The total world output of zirconium minerals in 1937 amounted to approximately 9,000 tons, of which Australia produced 58%, Brazil 26% and India 15%. The geographical distribution of the chief fields is shown in Fig. 29.

In 1952, Australia produced 30,320 long tons of zirconium minerals (zircon); Brazil, 2,165; Egypt, 118.



Distribution of chief ore-deposits of Copper, Lead, Zinc and Tin

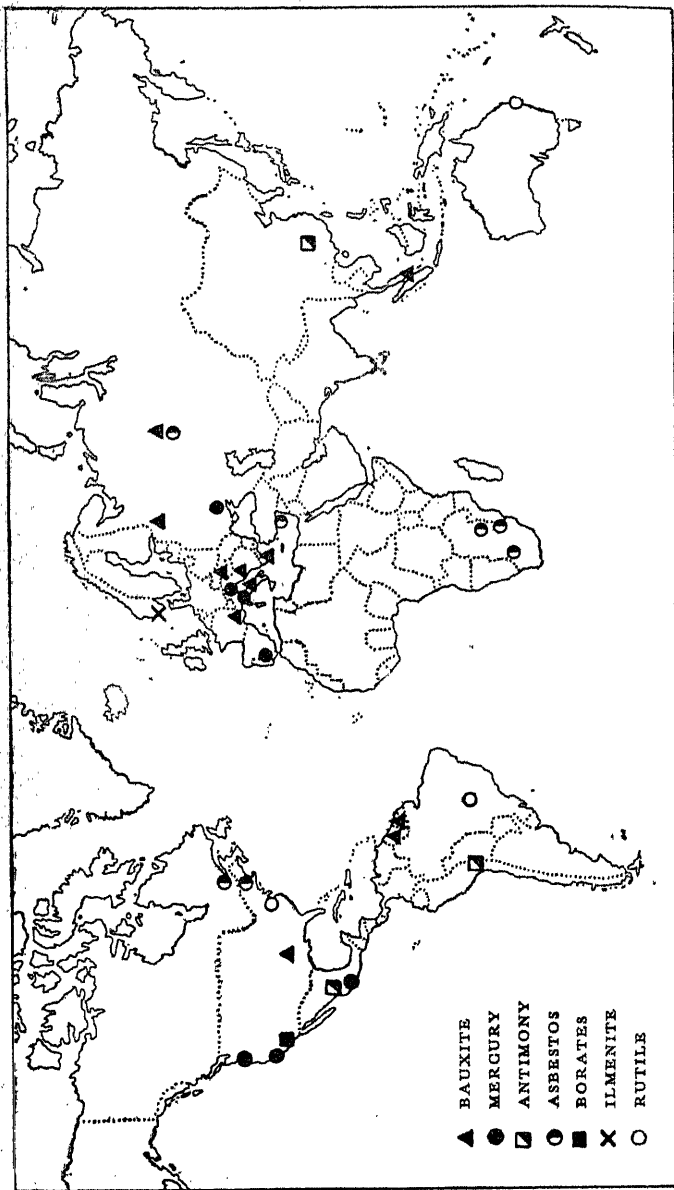


Fig. 28. Distribution of the chief deposits of Bauxite, Mercury, Antimony, Asbestos, Borates, Ilmenite and Rutile.

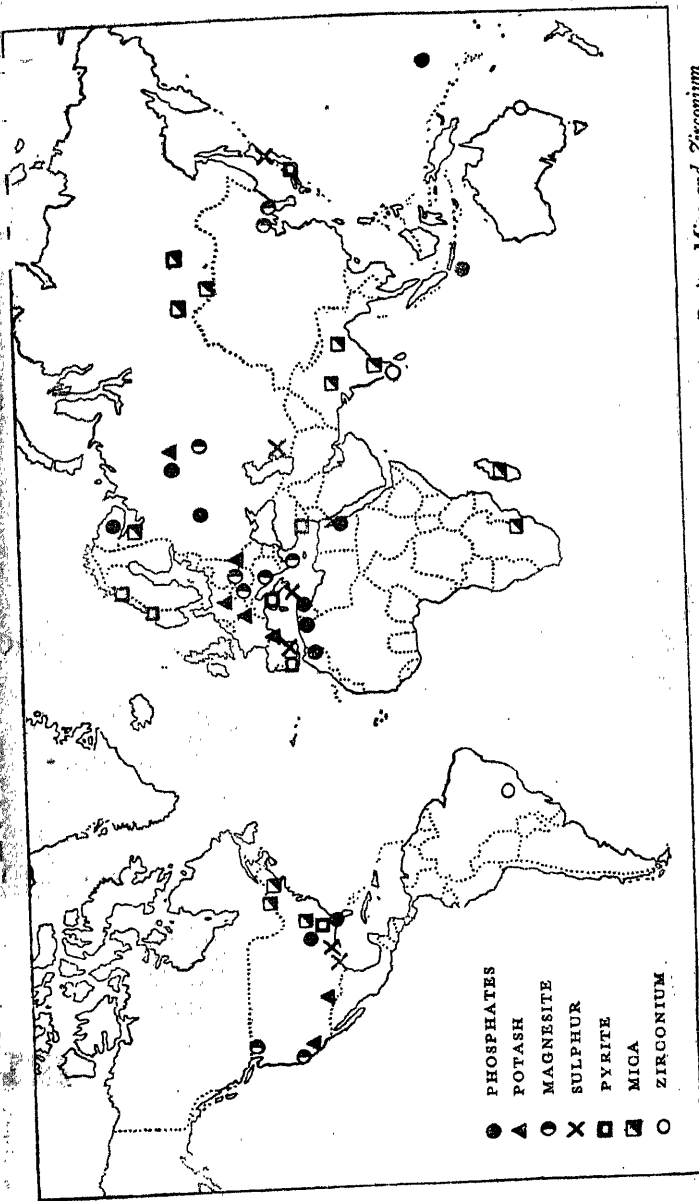


Fig. 29. Distribution of the chief deposits of Phosphates, Potash, Magnesite, Sulphur, Pyrite, Mica and Zirconium



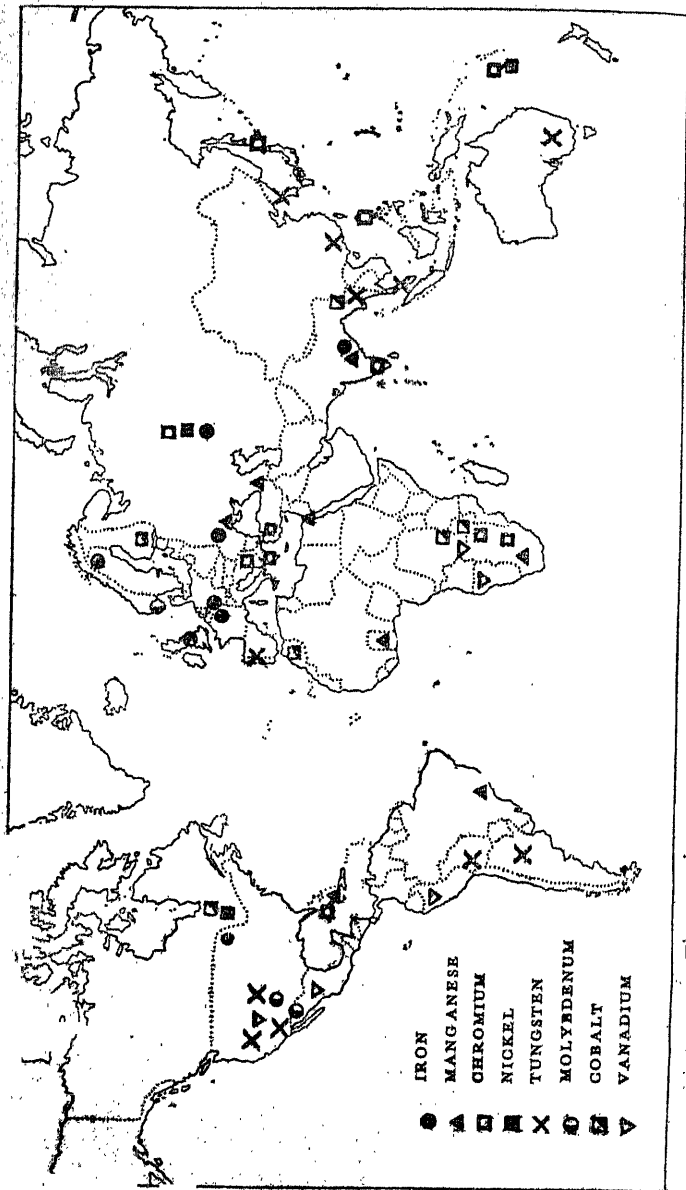


Fig. 30. Distribution of the chief ore-deposits of iron and ferro-alloy metals.  
 Areas with less than 10% of the world's reserves.

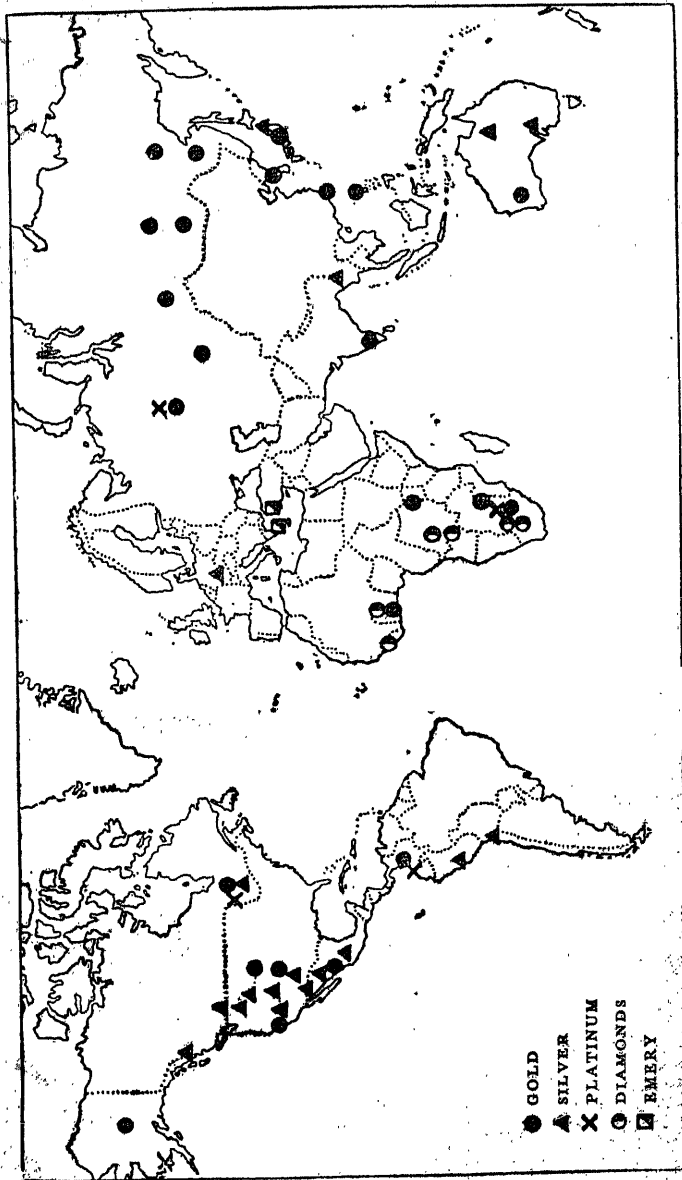
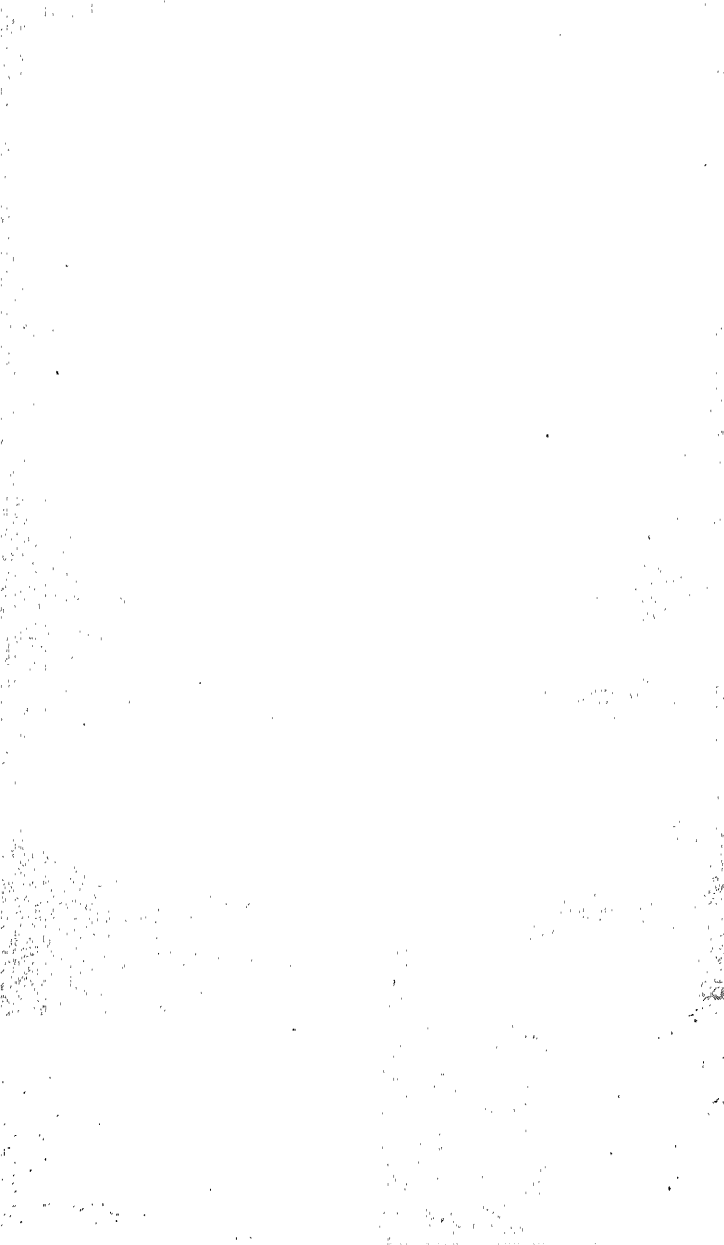


Fig. 31. *World Distribution of Gold, Silver, Platinum, Diamonds and Emery*



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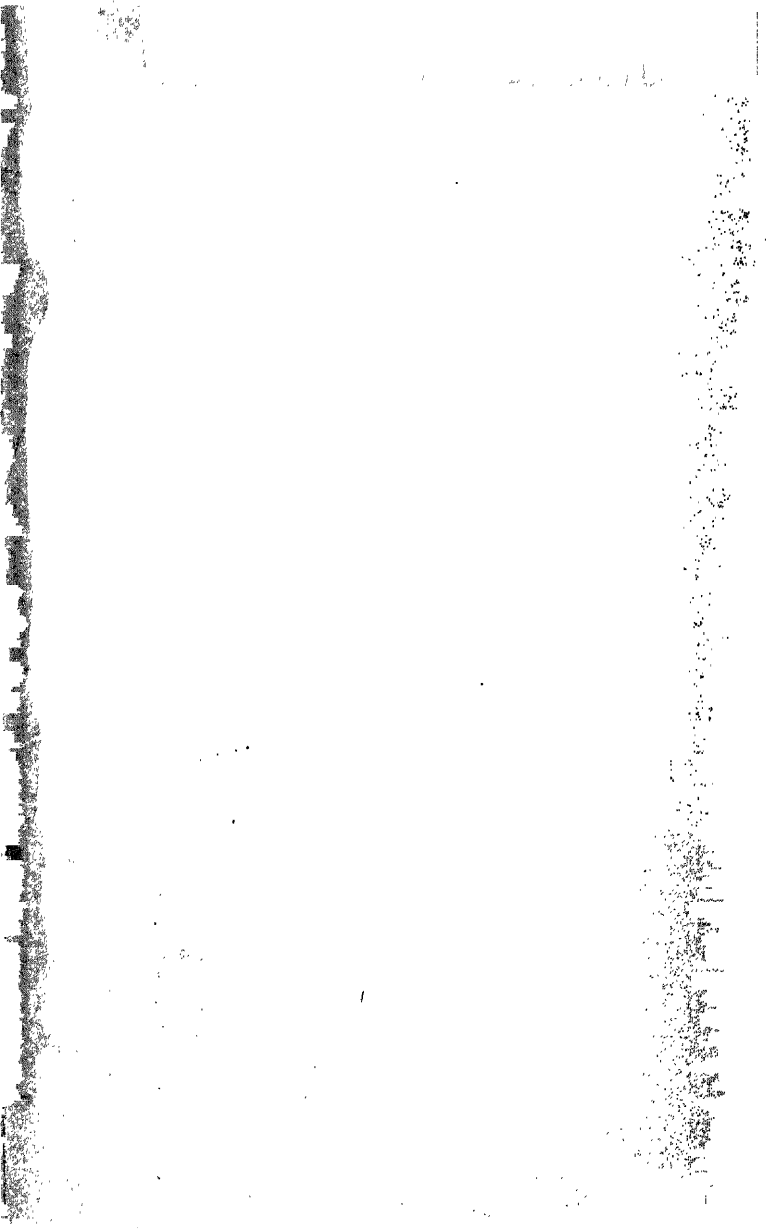
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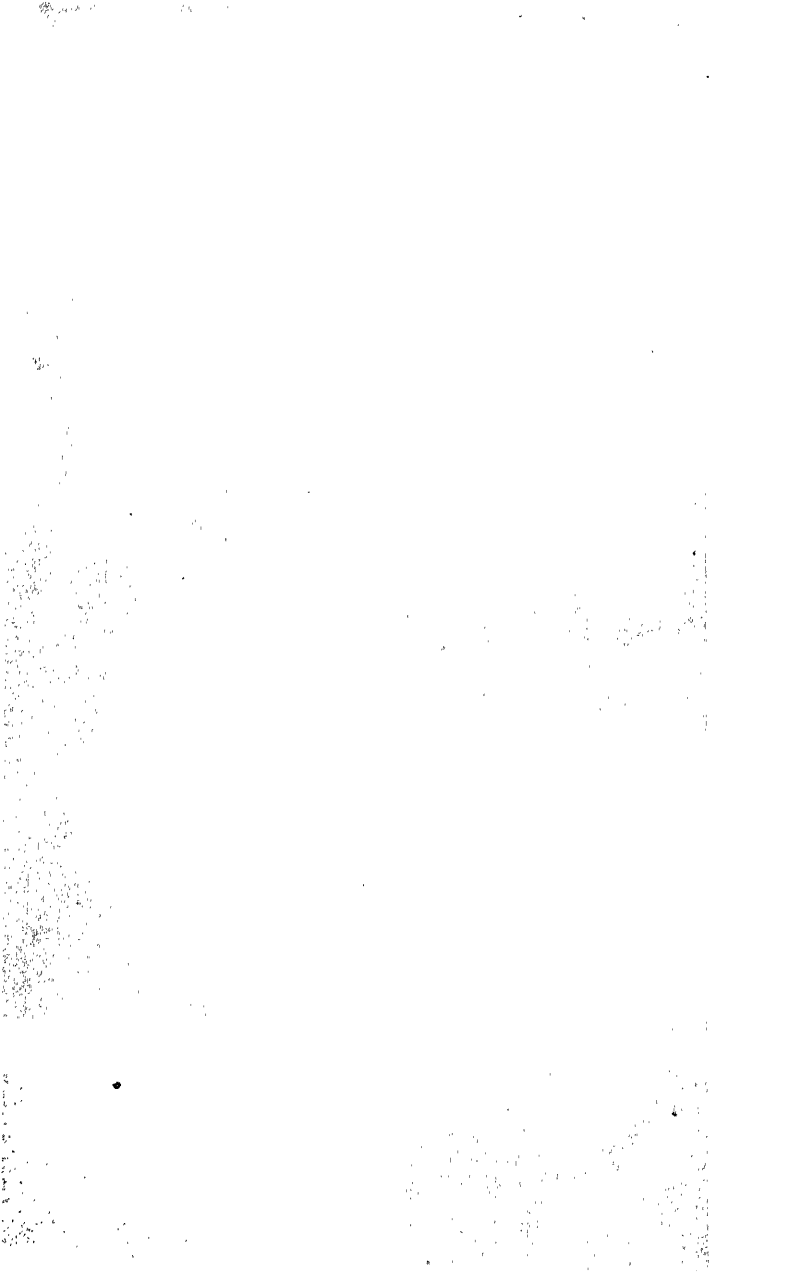
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